QUESTIONS

ON

MAGNETISM & ELECTRICITY

F. W. LEVANDER

SECOND EDITION.

SOLUTIONS OF QUESTIONS

ON

MAGNETISM AND ELECTRICITY

SOLUTIONS OF THE QUESTIONS

ON

MAGNETISM AND ELECTRICITY

SET AT THE

INTERMEDIATE SCIENCE AND PRELIMINARY SCIENTIFIC
PASS EXAMINATIONS

OF THE

UNIVERSITY OF LONDON FROM 1860 TO 1884

TOGETHER WITH

DEFINITIONS, DIMENSIONS OF UNITS, MISCELLANEOUS EXAMPLES, ETC.

BY

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PREFACE TO THE FIRST EDITION.

It frequently happens that persons, desirous of presenting themselves for Examinations, are deterred from doing so by a want of some further information as to the requirements of the Examiners than can be gained from a mere syllabus, or from the inspection of a few examination papers.

It has been thought, therefore, that a progressive arrangement of all the questions on Magnetism and Electricity set at the Preliminary Scientific and First B.Sc. Pass Examinations of the University of London during twenty years, with answers in full, would be serviceable to those who desire to pass either of those Examinations, as well as to others who study the Science without such ulterior object.

It will be seen that the same ground is covered by other examinations, such as the Oxford and Cambridge Local, those held under the Irish Intermediate Education Act, the Military Entrance Examinations, etc. It has

been considered advisable to prefix the Dimensions of Units which are required for more advanced questions.

I have to express my obligations to those writers whose labours have placed them in the foremost rank of authorities on Electrical Science, and whose works have in some instances, unacknowledged elsewhere, been freely laid under contribution.

The present Edition has been almost entirely re-written and enlarged by the insertion, in their proper places, of the questions set during the last five years.

July 13th, 1885.

For a very complete list of works on the subject the student is referred to *The Bibliography of Electricity and Magnetism*, by G. May, 1884.

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*** The questions in each section are arranged in progressive order, but similar ones set in different years are not repeated.

UNIVERSITY OF LONDON:

Syllabus of requirements for the Preliminary Scientific Examination and the Intermediate Pass Examination in Science.

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DEFINITIONS AND DIMENSIONS.

Mass = M, Length = L, Time = T, Area = L^2, Volume = L^3, Velocity = LT^{-1}, Acceleration = LT^{-2}, Momentum = MLT^{-1}, Density = ML^{-3}, Force = MLT^{-2}, Work = ML^2T^{-2}.

In the centimetre-gramme-second (C.G.S.) system, in which the centimetre, gramme and second are taken as the units of Length, Mass and Time respectively, the Unit of *force* is called the *Dyne*, and is that force which, acting on a gramme for one second, gives it a velocity of one centimetre per second.

The Unit of *work* is called the *Erg*; and is the amount of work done by one dyne working through a distance of one centimetre.

The Unit of *energy* is also called the *Erg*; energy being measured by the amount of work which it represents.

The Unit of *resistance* is called the *Ohm*, and $=10^9$ C.G.S. absolute units. At the International Congress of Electricians held at Paris in 1881, it was determined that the ohm should be represented by a column of mercury having one square millimetre of section, and a length to be determined hereafter. This length will be between 104·5 and 105 centimetres.

The Unit of *electromotive force* is called the *Volt*, and $=10^8$ absolute units. The electromotive force of one Daniell's cell is 1·079 volts.

The Unit of *current* is called the *Ampère*, (formerly known as the *Weber*), and $=10^{-1}$ absolute units. It is the current produced by one volt working through one ohm.

The Unit of *quantity* is called the *Coulomb*, and $=10^{-1}$ absolute units. It is defined by the condition that one ampère yields one coulomb per second.

The Unit of *capacity* is called the *Farad*, and $=10^{-9}$ absolute units, and is such that one coulomb in a farad shall give one volt.

In the words of Sir W. Thomson, "The volt acting through an ohm gives a current of one ampère, that is to say, one coulomb per second; and the farad is the capacity of a condenser which holds one coulomb, when the difference of potential of its two plates is one volt."

Dr. Siemens suggests also the following:—

The *Watt* (10^7 absolute units) as the unit of *power;* being the power conveyed by a current of one ampère in one second through a conductor, whose ends differ in potential by one volt; and

The *Joule* (10^7 absolute units) as the unit of work or heat; being the heat generated by one watt in one second.

Magnetism.

A *unit pole* is that which repels another similar and equal pole at a distance of one centimetre with a force of one dyne.

If P = the strength of a pole, it will repel an equal pole at the distance L with a force $\frac{P^2}{L^2}$ or P^2L^{-2}. Hence

$$P^2L^{-2} = MLT^{-2},\ P^2 = ML^3T^{-2},\ \therefore\ P = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}.$$

The *intensity* of a magnetic field is equal to one C.G.S. unit, when the force which acts on a unit magnetic pole placed in this field is equal to one dyne.

If I = this intensity, the force on a pole P will be IP.

Hence $IP = \frac{ML}{T^2}$ or MLT^{-2}.

Dividing both by P we have

$$I = MLT^{-2}.\,M^{-\frac{1}{2}}\,L^{-\frac{3}{2}}T = M^{\frac{1}{2}}\,L^{-\frac{1}{2}}\,T^{-1}.$$

The *moment* of a magnet is the product of the strength of either of its poles by the distance between them $= LP = M^{\frac{1}{2}}L^{\frac{5}{2}}T^{-1}$.

The *intensity of magnetisation* of a uniformly magnetised body is defined as the quotient of its moment divided by its volume and equals intensity of field.

$$\frac{\text{moment}}{\text{volume}} = M^{\frac{1}{2}}\,L^{\frac{5}{2}}\,T^{-1}.\,L^{-3} = M^{\frac{1}{2}}\,L^{-\frac{1}{2}}\,T^{-1}.$$

The work required to move a pole P from one point to another is the product of P by the difference of the magnetic potentials of the two points. Hence

$$\textit{magnetic potential} = \frac{\text{work}}{P} = ML^2T^{-2}.\ M^{-\frac{1}{2}}L^{-\frac{3}{2}}T = M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}.$$

Electro-Statics.

In the C.G.S. system the electrostatic unit of quantity is that which would repel an equal quantity, placed at the distance of one centimetre, with a force of one dyne. If Q denote the numerical value of a quantity of electricity in this measure, the mutual force between equal quantities Q at the mutual distance L will be $\frac{Q^2}{L^2}$, but in this system unit of force $= MLT^{-2}$, therefore $Q^2L^{-2} = MLT^{-2}$, whence $Q^2 = ML^3T^{-2}$ and $Q = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}$.

The work done in raising a quantity of electricity Q through a *difference of potential* V is QV. Hence

$$V = \frac{\text{work}}{Q} = ML^2T^{-2}.M^{-\frac{1}{2}}L^{-\frac{3}{2}}T = M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}.$$

There is *unit difference of potential* between two points when one erg is required to move a quantity of electricity, equal to one unit, from one point to the other, or $V = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}.L^{-1} = M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}$, as before.

The *capacity* of a conductor is one unit, when one unit of quantity of electricity raises its potential one unit, and is the quotient of the quantity of electricity with which it is charged by the potential which this charge produces in it. Hence

$$capacity = \frac{Q}{V} = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}.\ M^{-\frac{1}{2}}L^{-\frac{1}{2}}T = L.$$

The C.G.S. unit of capacity is the capacity of an insulated sphere of one centimetre radius.

The numerical value of a *current* (or the *strength of a current*) is the quantity of electricity that passes in unit time. Hence

$$\frac{Q}{T} = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}.$$

The dimensions of *resistance* can be deduced from Ohm's law, which states that the resistance of a wire is the quotient of the difference of potential of its two ends by the current which passes through it. Hence

$$resistance = M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}.\ M^{-\frac{1}{2}}L^{-\frac{3}{2}}T^{2} = L^{-1}T.$$

Or, the *resistance* of a conductor is equal to the time required for the passage of a unit quantity of electricity through it, when unit difference of potential is maintained between its ends. Hence

$$resistance = \frac{T \times V}{Q} = T.M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}.M^{-\frac{1}{2}}L^{-\frac{3}{2}}T = L^{-1}T,$$

as before.

Electro-Magnetics.

A current has a *strength* C equal to one C.G.S. unit if, when passing through a circuit one centimetre in length, bent into the form of an arc of a circle of one centimetre radius, it exerts a force of one dyne on a unit magnetic pole placed at the centre of the circle.

$$C = M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}.$$

The unit *quantity* of electricity Q is that quantity which passes through a circuit in one second, when the strength of the current is equal to one C.G.S. unit.

$$Q = M^{\frac{1}{2}}L^{\frac{1}{2}}.$$

The work done in urging a quantity of electricity Q through a circuit by an *electromotive force* E is EQ; also, the work done in urging a quantity Q through a conductor by means of a difference of *potential* E between its ends is EQ. Hence the dimensions of *electromotive force* and also the dimensions of *potential* are

$$E = \frac{W}{Q} = ML^2T^{-2}.M^{-\frac{1}{2}}L^{-\frac{1}{2}} = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}.$$

A condenser has a *capacity* equal to one C.G.S. unit if, when charged to a potential of one C.G.S. unit, it contains a quantity of electricity equal to one C.G.S. unit. Its dimensions are $L^{-1}T^2$.

A conductor has a *resistance* equal to one C.G.S.

unit, when unit difference of potential between its two ends causes a unit of current to pass through it. Its dimensions are LT^{-1}.

The *heat* generated in time T by the passage of a current C through a wire of resistance R (when no other work is done by the current in the wire) $= \frac{C^2RT}{J}$ gramme-degrees, where J [Joule's equivalent] $= 4{\cdot}2 \times 10^7$ ergs; and this is true whether C and R are expressed in electro-magnetic or electro-static units.

SOME OF THE MORE IMPORTANT LAWS.

1. The force of *magnetic attraction* or *repulsion* varies inversely as the square of the distance.

2. The force of *attraction* or *repulsion* between two *electrified* bodies, whose sizes are very small compared with their distance apart, varies inversely as the square of their distance. If their distance is more than one centimetre, the force equals the product of the charges divided by the square of the distance.

3. The electric *density* at any point of a surface, when the density is uniform, is equal to the quantity of electricity on each square centimetre of surface.

4. The *capacity* of an insulated spherical conductor is numerically equal to its radius.

5. The *directive action* of a current on a magnet is such that the marked end is always deflected to the left of the current.

6. The *strength of a current* is equal to the electromotive force divided by the resistance.

7. The *heat* disengaged in a given time is directly proportional to the square of the strength of the current and to the resistance.

8. Whatever be the length of a wire, if its diameter is uniform and if the same quantity of elec-

tricity passes, the *increase of temperature* is the same in all parts of the wire.

9. For the same quantity of electricity the *increase of temperature* in different parts of a wire is inversely as the fourth power of the diameter.

10. The same electric current *decomposes* chemically equivalent quantities of all the bodies which it traverses, and therefore the weights of elements separated in these electrolytes are to one another as their chemical equivalents.

11. Two *parallel currents* in the same direction attract, but in the contrary direction repel, each other.

12. The *direction of the Ampèrian currents* at the south pole of a magnet is the same as that of the hands of a clock, and the contrary at the north pole.

SOLUTIONS OF QUESTIONS

IN

MAGNETISM AND ELECTRICITY.

A. MAGNETISM.

1. If you were provided with bar magnets how would you proceed to make another permanent magnet? Point out which will be the North pole of the magnet so made. State the phenomenon of Secondary Poles and point out how you could produce such poles. (1862).

If I had only two magnets I should place the North pole of the one and the South pole of the other, nearly, but not actually, in contact, on the middle of the bar to be magnetised. Then, raising the other ends of the magnets so as to make an angle of about 30° with the bar, I should draw them apart as far as the ends of the bar. Replacing them in their first position, I should repeat the above process several times on both sides of the bar. The North pole will be that which was rubbed by the South pole of the inducing magnet. It would be better if the ends of the bar were placed on the poles of two other magnets, these poles being in the same position as those of the inducing magnet.

By Secondary, or Consequent, poles we mean that a magnet has more than two poles. They can be produced during the process of magnetisation, by rubbing one end of the bar more frequently than the other, or, better, by enclosing the bar in a helix, which has the direction of its turns changed several times, and then sending a current from a battery through it.

2. You are required to magnetise an iron bar permanently by the inductive action of the earth; how will you do it? Describe the polarity excited in the bar and state the difference between a bar of iron and one of steel when subjected to this process of magnetisation. (1861).

The bar must be kept for some time in a position parallel to that of the dipping needle; this will make it temporarily magnetic. To render the effect more permanent, the bar should be sharply struck a few times with a mallet,—the torsion caused by the blow appearing to increase the coercive force or retentivity. If a steel rod is held in the same position, it will be permanently magnetised without being struck. The lower end will be the marked pole.

3. What happens to a bar of soft iron if held in a vertical position in the latitude of London? (1881).

It will gradually become temporarily magnetic from the magnetism of the earth.

4. State and explain what takes place when a magnet is broken in the middle. (1877).

Each part becomes a perfect magnet with opposite poles, showing that all the molecules of the original magnet are in the same peculiar polarised condition.

5. Explain how keepers serve to maintain the magnetism of permanent magnets. (1867).

Being acted upon by Induction a keeper becomes a temporary magnet, its north pole being that in contact with the south pole of the magnet; it, therefore, diminishes the magnetic field and tends to maintain the strength of the magnet.

6. When a number of equal magnets are combined to form a magnetic battery, explain why the power of the battery does not vary as the number of magnets combined. (1868).

A great deal of their power is lost by the enfeebling action of each magnet on its neighbour, since each pole will induce on its neighbour magnetism of the opposite character.

7. Describe exactly experiments by which a bar of steel and a similar bar of soft iron could be distinguished from each other in consequence of their different magnetic properties. (1871).

If a bar of steel is rubbed with a magnet it will retain its magnetism; whereas if a bar of soft iron is similarly treated, its magnetism will be only temporary. Or, if a wire is coiled round a steel bar, and a current sent through the wire, the bar

will be permanently magnetised: if a bar of soft iron is similarly treated, it will retain its magnetism only so long as the current passes.

8. Explain the difference in the behaviour of soft iron and steel with respect to magnetisation. (1881).

Steel has greater retentivity than soft iron, which, unlike steel, easily acquires and easily loses magnetism.

9. A piece of soft iron is placed at right angles to the magnetic meridian, and a freely suspended magnetic needle is caused to approach its two ends in succession: what occurs? The bar is then set upright, and the needle, first brought near to its upper end, is gradually lowered along the bar to its bottom: describe and explain the effects observed. (1860).

If the bar is placed at right angles to the magnetic meridian, the needle is equally attracted at both ends; but if it is placed upright it becomes temporarily magnetic through the inductive action of the earth, and the marked pole of the needle is attracted to its upper end. This attraction, as the needle is lowered, gradually lessens till, at the centre of the rod, both poles are equally distant from it. Further down, the south pole is gradually attracted and at the bottom points direct to the rod.

10. What is meant by an Astatic combination of two magnetic needles? (1867).

By an Astatic combination is understood two magnetic needles of equal intensity, rigidly connected by a metal strap with their poles reversed.

11. A magnetic needle is suspended horizontally and allowed to oscillate under the action of the earth's magnetic force. What effect will be produced on the oscillations by placing a plate of copper at a short distance below the needle? (1870).

Currents will be set up in the copper in such directions as tend to lessen the oscillations of the needle, the copper acting as a damper. (See also Nos. 12, 13, 14).

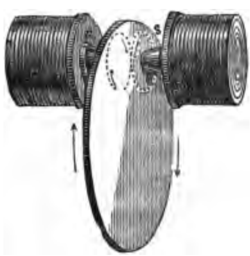
12. Give a description of a ship's compass. Why is it sometimes placed in a copper bowl? (1874).

A ship's compass consists of a magnetic needle supported at its centre of gravity on a pin and capable of moving in a horizontal plane. On its upper surface is fixed the graduated card. The box which contains the needle is weighted below and hung on gimbals, which consist of two metal rings, so arranged as to allow motion about two independent horizontal axes at right angles to each other. This arrangement permits the needle to be always horizontal and independent of the motion of the ship. The compass is sometimes placed in a copper bowl, since this acts as a damper, causing the needle to come more rapidly to rest through the action of the induced currents

set up in it by the oscillations of the needle. These currents tend to urge the needle in an opposite direction to that in which it is moving.

13. When a circular plate of copper is made to rotate about an axis through its centre, and perpendicular to the plate, between the poles of a powerful magnet, explain the cause of the resistance to the motion of the plate which is observed, and show by a diagram what is taking place in the plate at any instant. (1868).

It is caused by the currents set up, by induction, in a contrary direction to that in which, according to Ampère's theory, they circulate round the poles of a magnet. Or, in the words of Lenz's law, when a current is induced in a conductor by the motion of a magnet or current or of the conductor, the current induced flows in such a direction that its action opposes the motion producing



it. If a copper plate be made to revolve rapidly between the poles, *n*, *s*, of a powerful electro-

magnet, currents will be set up in it. The approaching part of the disc in the diagram has a south pole turned to *s* and a north pole turned to *n*. The receding part manifests the opposite polarity, both polarities being manifested on opposite sides of the disc and combining to resist its motion. If, however, the motion is persisted in, the temperature of the disc rises in proportion, according to Foucault, to the square of the velocity of rotation.

14. If you rotate a metallic disc between the poles of a powerful magnet the disc becomes heated. What causes this heat? and from what source is the energy producing it originally derived? (1865).

When the disc is rotated induced magnetic currents are set up in it. These soon become so considerable as to retard the motion of the disc, but if the motion is persisted in, the induced magnetism is converted into heat, which is the equivalent of the work done in maintaining the motion.

15. How did Coulomb apply the method of oscillations to prove that the attractive or repulsive force of two magnetic poles on one another varies inversely as the square of the distance? (1869, 1870).

A needle was first placed so as to be under the influence of the earth only, and the number of its oscillations in a certain time was counted. A bar magnet was then placed at a given distance in the magnetic meridian, and the oscillations of the

needle again counted for the same time as before. The magnet was moved to a definite distance and the oscillations again counted, when the number was found to vary inversely as the squares of the distance.

16. Describe the principle of measurement employed in the Torsion Balance.

A magnet suspended by a fine vertical wire hangs in the magnetic meridian when the wire is untwisted. If, on turning the upper end of the wire half round, the magnet is deflected through 30° from the meridian, show how much the upper end of the wire must be turned in order to deflect the magnet 45° or 60° respectively. (1884).

(1) Coulomb's Torsion balance depends on the principle that when a wire is twisted through a certain space, the angle of torsion is proportional to the force of torsion. It consists of a glass cylinder having its upper part covered by a glass plate, in the centre of which a circular hole is pierced, to the circumference of which is fixed a long vertical glass tube. At the upper end of the tube is a graduated fixed circle and a movable index. Attached to the index is a fine wire carrying at its lower extremity a well balanced magnetic needle. At the same level as the needle a graduated circle is engraved on the glass cylinder. There is likewise an aperture in the cover of the cylinder, through which a magnet may be introduced vertically. The amount of torsion neces-

sary to cause the pole of the suspended magnetic needle to approach, or recede from, the magnet introduced—according to the similarity or dissimilarity of the pole of the magnet introduced—through a certain number of degrees marked on the cylinder, is indicated by the number of degrees which the index has to be moved over the circle—called the torsion head. This is found to vary inversely as the square of the distance.

(2) If T, T′ = the angles of torsion and d, d' = the deflections,

then, since $T : T' = d : d'$,

$$\text{in (i) } 180^\circ : T' = 30^\circ : 45^\circ,$$

$$\therefore T' = \frac{45 \times 180}{30} = 270^\circ.$$

$$\text{in (ii) } 180^\circ : T' = 30^\circ : 60^\circ,$$

$$\therefore T' = \frac{60 \times 180}{30} = 360^\circ.$$

17. Describe the method of determining the law of repulsion of two magnetic poles by means of Coulomb's Torsion balance. (1880).

A magnetic needle is attached to the fine wire, and the instrument is so adjusted that, when in the magnetic meridian, it points to the zero of the scale on the glass cylinder. The magnetic needle is then removed and instead of it another similar one of copper is attached to the wire, and the torsion head turned so that the copper bar stops at zero of the graduation. The magnetic needle, being replaced, is now exactly in the magnetic

meridian and no torsion is exerted by the wire. Coulomb found that the index of the torsion head had, in one of the experiments, to be turned through 35° in order to turn the needle 1° from the meridian. (This amount will vary according to the dimensions and force of the needle, the dimensions and nature of the wire, and the intensity of the earth's magnetism at the place of observation). A magnet was now introduced into the aperture, so that similar poles of the magnet and needle were opposite each other. It was found that the pole of the needle was repelled through 24°. The force which tended to bring the needle into the magnetic meridian was represented by $24° + 24 \times 35 = 864$, of which 24° were due to the torsion of the wire and the remainder was the equivalent in torsion to the directive force of the earth's magnetism. By turning the index of the torsion head the needle was caused to make an angle of 12° with the meridian: in order to do this it was found necessary to move the index through $8 \times 360 = 2880°$. The total force which now tended to bring the needle into the meridian was composed of (1) the 12° of torsion by which the needle was distant from the meridian; (2) 2880°, the torsion of the wire; (3) the tension of $12 \times 35°$ representing the force of the earth's magnetism, making 3312 for 12° against 864 for 24°, showing that for half

the distance the repulsive force is (approximately) four times as great.

18. What is meant by a magnetic field? (1878, 1882).

The neighbourhood of a magnet where are all the magnetic lines of force, or, in other words, the region within which a magnet exerts its force.

19. A piece of iron is placed in a uniform magnetic field. How will the lines of magnetic force be affected? (1883).

When a piece of iron is placed in a magnetic field, it becomes magnetised, and the lines of force instead of continuing straight and parallel, as they are in a uniform magnetic field, will converge towards the extremities of the iron.

20. Define the magnetic moment of a magnet. Show how to measure the magnetic moment of a given magnet. (1878).

(1) A magnetic needle placed in a magnetic field across the lines of force experiences a "couple," *i.e.* a pair of forces tending to produce a motion of rotation. The north, or marked, pole is urged northwards, and the south pole southwards, with an equal and opposite force. The force acting on each pole is the product of the strength of the pole and the intensity of the horizontal component of the force of the earth's magnetism at the place of observation. The magnetic moment of a magnet is the product of the strength of either pole by its length.

(2) To determine the magnetic moment of a magnet a very short needle is suspended so as to hang in the magnetic meridian over a zero line. The magnet, whose moment is to be measured, is placed upon this line, at right angles to it and in the plane of the needle, at such a distance that it produces a deflection of only a few degrees. Let θ = angle of deflection, d = distance between the centre of needle and magnet, and H = the horizontal component of the Earth's magnetism; then $M = H\, d^3 \tan \theta$.

21. Define the *moment* and *intensity of magnetisation* of a magnet. (1881).

For the definition of magnetic moment see No. 20. The intensity of magnetisation of a magnet is the ratio of its magnetic moment to its volume.

B. TERRESTRIAL MAGNETISM.

22. State concisely all that you know regarding the magnetism of the earth, the position of its poles, and equator, the distribution of terrestrial magnetism and the variation which it has been proved to undergo. (1861).

The action of the earth on a magnet is simply directive, *i.e.*, it determines the position of the magnet relatively to the cardinal points, but causes no strain (or tendency to translation) on the point on which it is balanced. The North Magnetic Pole is situated in about lat. 70° N. and long. 96½°

W. The South Magnetic Pole of the earth has not been reached.

The magnetic equator is an irregular line where there is no dip. Terrestrial magnetism varies in different places; the isoclinic lines (those passing through places where the dip is the same) are not parallel to the equator, nor are the isogonic lines (those passing through places where the declination, *i.e.*, variation from the astronomical north, of the needle is the same) parallel to a meridian. The magnetic needle is subject to steady variations of long period, also annual and diurnal variations, as well as to irregular short-lived movements dependent on currents in the earth, which probably owe their origin in great measure to the heating power of the sun. The needle is also irregularly affected by the Aurora. (See also No. 23).

23. Describe the earth as a magnet. State what you know about its poles and its equator, and describe the behaviour of a compass-needle and of a dipping-needle, when carried from place to place on its surface. (1862, 1878).

Whatever may be the cause of the earth's magnetism, it may be regarded as to its effects in the light of a huge magnet, having in the northern hemisphere a pole which attracts the marked pole of a freely suspended magnet, and in the southern hemisphere one which attracts the other end of the same magnet. In this way the phenomena exhibited by compass and dipping-needles

may be readily explained. If we place a compass-needle at the centre of a bar-magnet, it will set at right angles to the latter, but on causing it to approach either pole, the contrary pole of the needle will be attracted. If a dipping-needle is placed at the centre of a bar-magnet, neither extremity will be affected; but as it is moved nearer either pole, its contrary pole will be gradually attracted, till it eventually assumes a vertical direction. These are precisely the same effects as are observed in the case of the earth. As a dipping-needle is carried from the line of no dip towards the magnetic pole, its dip becomes greater, till at the pole it would stand vertical; while a compass-needle would at the pole be at rest in any position. The magnetic poles do not coincide with the geographical; they are not diametrically opposite, nor do their positions remain unchanged. (See also No. 22).

24. If we call that the *marked* pole of a magnetic needle which points to the north, and if the earth be viewed as a large magnet, state generally the position of the *marked* pole. (1863).

In the southern hemisphere, as indicated by the dip of the unmarked pole of the dipping-needle.

25. Define the terms (as applied to the earth) magnetic meridian, magnetic equator, magnetic pole. How would a ship's compass behave in the neighbourhood of a magnetic pole? (1867).

The magnetic meridian is an imaginary plane,

drawn through the zenith, and passing through the magnetic north and south points of the horizon. Its direction is indicated by the position assumed by a magnetised needle moving in a horizontal plane. (For the rest of the question, see Nos. 22 and 23).

26. What is meant by the terms inclination, declination, horizontal intensity, total force, as applied to magnetism? (1860, 1865, 1866, 1877).

By inclination is meant the angle which a magnetic needle, suspended so as to move in a vertical plane coinciding with the magnetic meridian, makes with the plane of the horizon. It is also called the dip.

By declination is meant the angle which the magnetic meridian, as indicated by the position of a magnetic needle, suspended so as to move in a horizontal plane, makes with the astronomical meridian.

The horizontal intensity is that force which causes the needle to settle in the magnetic meridian.

The total intensity is the whole force of the earth's magnetism, and = the quotient of the horizontal intensity by the cosine of the dip.

27. Explain the terms declination, dip, total intensity, as applied to terrestrial magnetism. What is meant by "secular change" and what by "disturbance," with reference to any one of the three elements mentioned above? What other

phenomena are connected with disturbance of terrestrial magnetism? (1874).

For explanation of the terms, see No. 26.

Those changes which require a long time to complete their cycle are called *secular*; such are the slow changes in declination and inclination. The term ***disturbance*** is applied to those temporary magnetic storms, by which the needle is irregularly affected, such as those caused by the Aurora, and by outbursts of solar spots.

28. Define the terms declination, dip, and diurnal variation, as applied to terrestrial magnetism.

A bar magnet which is capable of turning in any direction about a fixed point rests with its axis horizontal. How must the fixed point be situated with respect to the centre of gravity of the bar, if the magnet be (1) in London, (2) at the Magnetic Equator, (3) at Cape Town? (1879).

For declination and dip, see No. 26.

Diurnal variation is the term applied to a slight daily movement of the needle, differing in different places. It occurs both in declination and dip. As regards the former, soon after midnight the marked pole moves eastward, attains its maximum in about 6 or 7 hours, and, on its return journey, passes the mean magnetic meridian at about 10 a.m. In about 3 hours it reaches its extreme daily westerly range, passing the mean again at about 5 p.m. It is to this movement in declination that the term is usually applied.

The magnet would be subject to two forces, that of gravity, and that due to terrestrial magnetism. At the magnetic equator the fixed point and the centre of gravity will coincide; at London the former must be nearer the marked pole, but at Cape Town nearer the unmarked, in order to preserve the horizontality of its axis.

29. Define the terms *horizontal intensity*, *vertical intensity*, and *dip*, as applied to terrestrial magnetism, and state the relation between them. (1881).

Horizontal intensity and dip are explained in No. 26.

Vertical intensity is that force which tends to cause a needle to assume a vertical position.

$$\begin{aligned} \text{Let } \mathrm{H} &= \text{horizontal intensity,} \\ \mathrm{V} &= \text{vertical intensity,} \\ \mathrm{T} &= \text{total intensity,} \\ \theta &= \text{angle of dip.} \\ \mathrm{T} &= \mathrm{H} \sec \theta, \\ \text{and } \mathrm{V} &= \mathrm{T} \sin \theta, \\ \therefore \mathrm{V} &= \mathrm{H} \tan \theta. \end{aligned}$$

30. Describe the most accurate method you are acquainted with for finding the magnetic meridian of a place experimentally, giving reasons for any precautions that are necessary. (1872).

A telescope is placed at some little distance from a carefully suspended magnet, which carries at the end nearest the telescope a small lens, and at the other a cross of wires, the distance between them being equal to the focal length of the lens. The

position of the telescope is noticed on a horizontal graduated circle; it is then turned so that the centre of the cross wires on the magnet may appear to coincide exactly with the centre of those fixed in the eye-piece of the telescope. The magnet is inverted, in order to counteract any errors of suspension, and the observation repeated. The magnet is then re-magnetised with its poles reversed, to counteract any irregular magnetisation due to the quality of the steel, and the two observations repeated. The mean of the difference between the astronomical meridian and the positions of the telescope, at the four observations, will show the position of the magnetic meridian with respect to the astronomical.

31. What do we need besides magnetic declination and dip, to know completely the present state of the earth's magnetism at any point? (1865, 1866).

The horizontal intensity at the given place.

32. If required to ascertain the relative magnetic intensity at two points of the earth's surface, how would you proceed to do it? (1860, 1881).

It is necessary to observe at each place the oscillations which a horizontally suspended needle will make in any equal times, when disturbed from its position of rest, and the dip. From the former will be obtained the horizontal intensity, which is proportional to the squares of the number of oscillations at each place. This divided by the

cosine of the dip will give the total intensity for each place. The observations must be made with the same two needles.

33. Let the horizontal magnetic force be 3·8, and the vertical force 8·5; find the total magnetic force. (1877).

Total force $=\sqrt{(3{\cdot}8)^2+(8{\cdot}5)^2}=\sqrt{14{\cdot}44+72{\cdot}25}$ $=\sqrt{86{\cdot}69}=9{\cdot}31$.

34. In making an observation of dip, I first of all bring the circle into such a position that the needle points vertically up and down. Show that it is now swinging in a plane perpendicular to that of the magnetic meridian. (1873).

A needle when at right angles to the magnetic meridian is vertical, because in that position it is acted on by the vertical component only, the horizontal component being ineffectual to move it.

35. What is meant by the dip of the magnetic needle? Describe a dip-circle, and show how, by means of such an instrument, the local magnetic meridian may be determined. (1876).

By the dip is meant that one end of a magnet, free to move in a vertical plane, points more or less downwards. In places north of the magnetic equator this will be the marked pole.

A dip-circle consists of a magnetised needle very carefully mounted, so as to move with as little friction as possible, on a horizontal axis, in such a way that the centre of suspension corresponds with the centre of gravity of the needle, and

playing on a vertical graduated circle. The whole is capable of being rotated in a horizontal plane and its position noted on a horizontal circle. It is also provided with microscopes for reading the graduations, and with levelling screws. The instrument is so placed that the needle is vertical; it is then turned 90° on the horizontal circle, and the plane in which it now swings is that of the local meridian.

36. The centre of gravity of a dip-needle does not quite coincide with its axis of suspension. Describe the operations necessary in order to eliminate the error which would otherwise arise in the measurement of the magnetic dip. (1883).

Having observed the dip as indicated by the instrument, the magnetism of the poles of the needle is reversed, and the observation repeated. The mean of the two observations will give the true amount of the dip.

37. Describe a method of determining the magnetic dip by the revolution of a coil of wire about an axis in its own plane. (1882).

If the axis on which the coil turns is placed so as to cut the magnetic meridian at right angles, and a current from a battery is sent through the coil, the latter will place itself in a direction at right angles to that of the dipping-needle at the place of observation.

38. A magnetic needle is carried from London to another locality, and is there made to vibrate

in a horizontal and also in a vertical plane. It is found that the former description of vibration is more rapid than that in London, while the latter is less so. What may be argued from these facts? (1868).

As we go northward or southward from the magnetic equator, or line of least intensity, the total intensity increases, but the horizontal diminishes. It therefore happens that a compass-needle will oscillate more slowly as we leave the magnetic equator, but the reverse is the case with the dipping-needle. Consequently in this instance the needle has been carried to a place nearer the magnetic equator than London.

39. A declination needle makes 50 oscillations in one minute at a point on the earth's surface where the inclination is 60°, and 57 oscillations in a minute where the inclination is 45°. Compare the magnetic intensities at the two places. (1869).

Intensities at the two places

$$=\frac{50^2}{\cos 60^\circ}:\frac{57^2}{\cos 45^\circ}=\frac{57^2\cos 60^\circ}{50^2\cos 45^\circ}$$

$$\begin{array}{llll}
\log\cos 45^\circ & = 9{\cdot}8494850, & \log\cos 60^\circ & = 9{\cdot}6989700 \\
\log 50^2 & = 3{\cdot}3979400, & \log 57^2 & = 3{\cdot}5117498 \\
\hline
 & 13{\cdot}2474250 & & 13{\cdot}2107198 \\
 & 10 & & 10 \\
\hline
\end{array}$$

$\log 1767{\cdot}7315 = 3{\cdot}2474250$, $\log 1624{\cdot}5 = 3{\cdot}2107198$

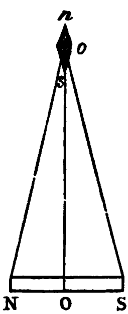
$\therefore$ intensities are as $1767{\cdot}7315 : 1624{\cdot}5 = 1{\cdot}0882 : 1$.

40. A magnetic needle, the magnetic moment of which remains constant, is suspended so as to move freely in a horizontal plane. When deflected from the magnetic meridian at three different places on the earth's surface, it is observed to oscillate 7·5, 8·3, 10·4 times respectively in one minute. Compare the intensities of the earth's horizontal magnetic force at the three places. (1875).

$$(7{\cdot}5)^2 : (8{\cdot}3)^2 : (10{\cdot}4)^2 = 56{\cdot}25 : 68{\cdot}89 : 108{\cdot}16$$
$$= 1 : 1{\cdot}225 : 1{\cdot}918.$$

41. Explain how to determine the ratio of the magnetic moment of a magnet to the earth's horizontal magnetic force. (1878, 1882).

Place a bar magnet, NS, with its axis perpendicular to the magnetic meridian and notice the deflection that it causes on a short magnet, *ns*, freely suspended, so that when in the magnetic meri-



dian, the prolongation, nO, of its axis, bisects the

angle NoS. The deflection, θ, of ns will depend on the relative magnitudes of the horizontal component of the earth's magnetic force, H, and the field produced by NS. Let $M =$ magnetic moment of the magnet and $r = oS = oN$, then $\frac{M}{H} = r^3 \tan \theta$.

C. STATIC ELECTRICITY.

42. How does it appear that the electricity developed by friction is of two kinds? Is that developed by rubbing a surface of glass always of one kind? Explain how the kind of electricity of any excited surface may be determined. (1860, 1861, 1869).

If glass, excited by having been rubbed with silk, is brought near a pith ball, the latter is attracted, and, having touched the glass, immediately repelled. This shows that it has received a charge from the glass, and, as magnetic poles of the same kind repel each other, so two bodies charged with electricity of the same kind repel each other. If the pith ball, while it is being repelled by the glass, is brought near a stick of sealing wax excited by having been rubbed with flannel, it will be attracted, showing that electricity of a different kind has been set up.

If glass is rubbed with silk it becomes positively

electrified; but negatively, if rubbed with flannel or cat's skin.

The kind of electricity of any excited surface may be determined by the use of a gold leaf electroscope. This consists of two gold leaves, attached to the lower end of a metallic rod which passes through an opening in the upper part of a bell glass and terminates in a brass knob or plate. The electrified body (or a portion of its charge) is brought near the knob. Electricity of the same sort is repelled into the leaves, making them diverge, while unlike electricity is attracted into the knob. The knob is touched with the finger; leaves, rod and knob will now have a charge of the opposite character to that of the influencing body. If the finger is removed and then the influencing body, the leaves, which had collapsed when the knob was touched, again diverge. Two uninsulated strips of metal, fixed to the inside of the bell jar, are inductively electrified by any charge on the gold leaves; the strips therefore attract the leaves and increase their divergence. If an excited glass rod is gradually brought near the knob and causes a diminution of divergence, the influencing body was electrified positively, but negatively if it causes an increase of divergence.

43. Describe experiments which show the existence of two different electrical conditions, and the propriety of the terms "positive" and "negative" as applied to them. (1861, 1868).

If an insulated conducting ball, A, is electrified by contact with rubbed wax, and another similar ball, B, electrified by contact with rubbed glass, and the two balls made to touch, they will, if equally charged, both assume the same neutral electrical condition; but if A had more electricity at first, the whole system will be electrified as if by rubbed wax, and *vice versa;* and, always, the quantity of electricity on the two balls after contact is equal to the difference of charge on the two balls at first. The distinction between electricity due to rubbed glass and that due to rubbed wax, is therefore analogous to that between + and — algebraic quantities. (See also No. 42).

44. What proofs have we of the identity of the electricity developed by friction with that developed by the action of an acid and two metals? (1862, 1865).

By connecting one binding screw of a galvanometer with the prime conductor of an electrical machine in action and the other with the earth, the needle may be deflected. Also, water may be decomposed by frictional, and a Leyden jar charged by voltaic, electricity.

45. Give a proof that statical electricity, though of high intensity, is very small in quantity. (1866).

The difficulty with which a galvanometer needle is deflected or water decomposed, both of which are easily done by voltaic electricity, the intensity of which is slight, will serve as a proof.

46. Two pith balls are suspended from a brass stand, the one by a silk, the other by a cotton, thread. A piece of excited glass is found first to attract and then to repel the pith ball with the silk thread, while it continues to attract the pith ball with the cotton thread. Explain this. (1877).

The ball which is attached to the silk thread is insulated, and is neutral. The glass being positively electrified attracts the ball and communicates some of its charge to it, thereby causing repulsion. The second ball is uninsulated and will continue to be attracted on account of the negative electricity induced on it.

47. A large insulated metallic cylinder, brought near the cap of a positively charged gold leaf electroscope, diminishes the divergence of the leaves. Show whether this effect affords *any* conclusive evidence as to the electrical condition of the cylinder, and if so, *what* it indicates. (1872).

The cylinder was charged with negative electricity; the divergence of the leaves is diminished because the positive electricity was attracted to the knob by the presence of the cylinder.

48. If a number of insulated bodies, some charged positively and some negatively, be suspended within an insulated tin canister, what will be the condition of the outside of the canister, and under what circumstances will it possess no charge? (1882).

Each of the charged bodies will induce upon the

outside of the canister an equal quantity of electricity of the same kind as its own charge. Hence the final charge of the canister is the algebraic sum of the charges of the several bodies. If a_1, a_2, a_3 represent the charges of positive, and b_1, b_2, b_3 those of negative, electricity, the final charge will be $\Sigma a - \Sigma b$.

49. An insulated metallic cylinder, uncovered at the top, is connected by a wire with the cap of an electroscope. A charged brass sphere is slowly lowered, by means of a silk thread, into the cylinder, until it touches at the bottom; after which it is withdrawn. State and explain the behaviour of the electroscope during the course of the experiment. (1877).

If the sphere is charged with, say, positive electricity, as it is lowered into the cylinder, the leaves of the electroscope will diverge with positive electricity and will continue to do so until the sphere is about $\frac{2}{3}$ from the bottom of the cylinder, when they will become stationary and remain so till, and after, contact. On removing the sphere it will be found to be perfectly discharged. This shows that the cylinder was charged by induction, and that the quantity of electricity thus developed on the outside of the cylinder must have been precisely equal to the charge on the sphere.

50. An insulated charged sphere is placed inside an insulated metal vessel. State fully what happens. The vessel is then touched with the

finger: what happens in this case? Finally the sphere is allowed to touch the inside of the vessel. What will be the charge finally left upon the hollow vessel? (1880).

The outer surface of the vessel assumes a charge equal and similar to that of the sphere, the inner surface gets a charge equal and opposite to that of the sphere. By touching the vessel with the finger, it is rendered neutral. If the sphere is then allowed to touch the inside of the vessel, the latter still remains neutral.

51. If a metal ball, hung by a dry silk thread, be made to touch the inside of an electrified metal jar, and then carried to an electroscope, the electroscope is not affected, but if the electroscope is connected with the inside of the jar by a wire, it receives a charge. Account for the difference between the two results. (1884).

The charge resides in the outer surface only of the jar, therefore the electroscope is not affected in the first case, as the ball is insulated. But when the electroscope is connected by a wire with the inside of the jar, an induced charge is transmitted by the metallic conductor to the electroscope, which is therefore affected.

52. Describe and explain the construction and use of the electrophorus. (1868, 1874).

The electrophorus consists of a metal disc with an insulating handle, and a disc of ebonite cemented to a metal plate or dish. To use it, the

ebonite is stroked with cat's skin, thereby negatively electrifying the upper surface. This induces a positive charge on the lower surface. The metal disc is then placed on the ebonite. Positive electricity is thereby induced on the under surface of the metal, and negative repelled to the upper; this latter is got rid of by touching the upper surface with the finger, unless the ebonite is furnished with a metal pin passing from its upper surface to the uninsulated dish. (A resinous cake may be used instead of ebonite). Positive electricity then spreads over the whole surface of the metal disc, from which, when raised, a spark can be obtained. The ebonite will remain excited for a considerable time, but the process of placing the metal disc on the ebonite, touching it with the finger and raising it, must be gone through before a spark will pass.

53. In the common electrical machine, state and explain the effect of insulating the rubber. (1862).

But little electricity can be collected, the mutual attraction of the electricities of both conductors acting inductively on each other. If the prime conductor is connected with earth, negative electricity can be abundantly obtained from the rubber.

54. Explain the use of the prime conductor of an electrical machine. What differences are there in the electrical state of the conductor at different parts when the machine is at work? Explain

how these differences can be determined. (1863).

The use of the prime conductor is to accumulate the electricity which has been produced by the friction of the glass against the rubber and collected by the points. The part of the conductor nearest the glass plate will be charged with negative electricity, the further part with positive, while the central portion will be neutral. These different conditions can be determined by means of a proof plane and gold leaf electroscope.

55. State the results which ensue when a conductor is made to touch an insulated electrified body, (1) when the former is insulated, (2) when it is uninsulated. (1860).

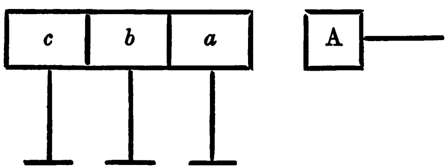
In the first case, the charge will be divided between it and the electrified body, in the ratio of their surfaces; the neutral electricity of the former being decomposed, that of the opposite sign is attracted to the side nearest the electrified body, while electricity of the same sign is repelled to the further side. In the second case, the whole of the charge will pass to the ground.

56. Describe experiments showing that the free electricity in a charged body is entirely upon its surface. How is this phenomenon explained? (1867).

If a hollow sphere, in which there is a small circular opening, is charged with electricity, the proof plane will show that the outer surface is charged; but if carefully introduced into the hole,

the edges of which should be well insulated, it will show that none resides on the inner surface. Again, if a conical muslin bag is set on an insulated ring, and so arranged that it may be turned inside out by means of a piece of silk fastened to its apex, the proof plane will show that the outer surface only is charged, whether the bag is inverted or not. This is due to the fact that each portion of a charge repels every other similar portion with a force inversely proportional to the square of the distance separating them.

57. A plate, A, is kept positively electrified, and three neutral metallic bodies, *a*, *b*, *c*, upon insulat-



ing feet, and in contact with each other, are made to approach A, but not so near as to receive a spark. When near A, first *c*, then *b*, then *a*, are successively removed by their feet; how will they be charged? (1864).

When in contact, *a* will be negatively and *c* positively charged, *b* being neutral. When *c* is removed it will be still positively charged; the

negative electricity on *a* will induce a charge of the opposite character on *b*, and when *b* and *a* are removed, the former will be positively charged and the latter negatively.

58. If a glass jar be electrified inside and be inverted on a table over pith balls, the balls begin to dance up and down; the motion presently ceases, and when on the point of ceasing may be renewed by simply passing the hands down the outside of the jar. Explain these phenomena. (1866).

The glass, being electrified, attracts the balls, each of which brings down some of the electricity from the glass. By passing the hands down the glass, the electricity on the outer surface is released, consequently the motion re-commences.

59. What is a disruptive discharge, and how does it differ from a charge by conduction? How is the light which attends such a discharge affected by the metals between which the discharge passes? (1860).

Induction across a non-conducting medium causes a stress upon it. If this is very great, the medium gives way, and what is called a disruptive discharge takes place. This is accompanied by light and noise, whereas a discharge by conduction is invisible and inaudible.

The different metals impart to the spark the characteristic colours which they exhibit when deflagrated. If wires are stretched on white paper and

deflagrated, the following colours will be left on the paper :—

Brass wire leaves purple and brown.

Copper, green, yellow and brown.

Gold, purple and brown.

Iron, light brown.

Lead, brown and bluish-grey.

Platinum, grey and light brown.

Silver, grey, brown and green.

Tin, yellow and grey.

Zinc, dark brown.

60. An insulated conducting cylinder is placed with one end near a positively charged ball; the point of the cylinder nearest to the ball is touched for an instant with the finger, and afterwards the ball is removed. State and explain the electrical effects which take place in the cylinder during the whole process. (1871).

An induced charge of negative electricity will be found on the end of the cylinder nearest the ball, and one of the opposite kind on the other. When *any part* of the cylinder is touched by the finger, the positive electricity escapes, leaving the cylinder charged with negative electricity.

61. Show how the inner coating of a Leyden jar can be negatively charged by means of a common electrical machine with uninsulated rubbers. Also show whether the strongest charge that can be given to the inner coating of the jar in this way is of the same strength as the strongest

charge that it can receive from the same machine, when it is charged in the usual way. (1871).

If the jar is held by the knob and the outer coating presented to the prime conductor of the machine, the inner coating will be negatively charged. As the capacity and potential will remain unaltered, the quantity will be the same in whichever way the jar is charged.

62. Explain the theory of the Leyden jar and show how to charge it. A quantity of electricity $= 5$ is conducted into the interior of a Leyden jar of surface $= 2$; and a quantity of electricity $= 6$ is conducted into the interior of a similar jar of surface $= 3$. Compare the heat developed by discharging each. (1875).

(1) A Leyden jar is merely a condenser, consisting of two conductors separated by a dielectric, and acting by induction. When the knob in connection with the inner coating of the jar is presented to the prime conductor of a machine in action, positive electricity accumulates on the inner surface of the inner coating; by induction a charge of the opposite character accumulates on the other side of the dielectric, *i.e.*, on the inner surface of the outer coating. The outer surface of the outer coating being in connection with the earth is at the same zero potential: if the two conductors were at the same potential, induction could not take place.

(2) The heat developed by the discharge of a

Leyden jar is directly proportional to the square of the quantity of electricity, and inversely proportional to the coated surface.

$$\therefore \frac{5^2}{2} : \frac{6^2}{3} = \frac{25}{2} : \frac{36}{3} = 25 : 24 = 1 : \cdot 96.$$

63. A, B and C are three Leyden jars, equal in all respects. A is charged, made to share its charge with B, and afterwards share the remainder with C, both B and C being previously without charge. The three jars are now separately discharged. Compare the quantity of heat resulting from each discharge with what would have been produced by the discharge of A before any sharing of its charge. (1884).

Let the original charge on $A = 1$, when this is shared with B the charge on each of A and B $= \frac{1}{2}$, and when the charge now on A is shared with C, there will be a charge on each of A and C equal to $\frac{1}{4}$. From the formula $H = \frac{Q^2}{S}$ (where H = the heat developed, Q = the quantity of electricity, and S = the coated surface), the heat developed by the discharge of A, before sharing its charge, would be represented by 1, by the final discharge of A by $(\frac{1}{4})^2 = \frac{1}{16}$, by that of B by $(\frac{1}{2})^2 = \frac{1}{4}$, and by that of C by $(\frac{1}{4})^2 = \frac{1}{16}$.

64. How would you charge a Leyden jar by means of an electrophorus already excited? (1862).

When the metal disc is in contact with the

ebonite, touch the former with the finger and then present it to the knob of the jar. Repeat the process until the jar is fully charged.

65. If a Leyden jar be charged in the ordinary way, state and explain the effect of touching the knob connected with the inner coating, when the jar is (1) insulated, (2) uninsulated. (1861).

If the jar is insulated, a small spark only will pass, the positive and negative electricities being unable to combine. If it is uninsulated, touching the knob will cause the jar to be discharged, connection between the two coatings being made through the body of the experimenter.

66. Two Leyden jars, one charged and one empty, are placed a little distance apart on a tray, and a wire is allowed to drop on the two knobs. Explain what would happen, supposing the tray made (1) of glass, (2) of metal. (1867).

If the tray is of glass a very small quantity of electricity passes into the uncharged jar, but, if of metal, the charge will be distributed between the two jars.

67. If a Leyden jar be discharged through a metal wire, state the several circumstances on which the heating of the wire depends. Suppose the wire to be a hollow pipe, what difference will this make? Give your reasons, or the general law applicable to the case. (1868).

The amount of heat developed not only depends on the quantity of electricity and the extent of

coated surface, but is also directly proportional to the resistance of the connecting wire. If a pipe is used, there will be a difference due to a difference of metallic area, since the heat varies, other things being similar, inversely as the fourth power of the diameter.

68. Describe the unit jar and explain its application to the measurement of the charge of a Leyden battery. (1870, 1880).

Lane's unit jar is a small Leyden jar, near which is a vertical metallic support connected with the outer coating. Through the upper part of this support slides a rod, furnished at one end with a knob which can be placed at a measured distance from the knob of the jar. To measure the charge of a battery by means of this instrument, the former is insulated and its outer coating connected with the inner coating of the uninsulated unit jar. When the battery is being charged, positive electricity passes into it, a proportionate quantity passing to the inner coating of the unit jar, and there producing a charge. When this has reached a certain limit, determined by the distance between the two knobs of the jar, a spark passes between them. This will happen as often as the same amount of electricity is added to the inner coating of the battery. The charge is measured by counting the sparks.

Harris' unit jar consists of a small insulated Leyden jar, one coating of which is connected

with the uninsulated battery, the other with the prime conductor of the machine.

For small distances, the striking distance is directly proportional to the quantity of electricity and inversely proportional to the extent of coated surface.

69. A Leyden jar is charged from an electric machine, a unit jar being interposed, and ten discharges of the unit jar occur. Compare the work done by the person working the machine in each successive time of charging the unit jar. (1880).

Since the unit jar remains of the same capacity throughout the experiment, it follows that the work required to produce each of the ten discharges must be approximately the same. Hence the work done is the same for each discharge.

70. Describe and explain the condenser. (1860, 1865).

This instrument consists of two insulated metallic plates, separated by, and capable of being placed at different distances from, a sheet of glass or other dielectric. One plate, A, is connected with the ground, the other, B, with the machine. Then, if the machine is worked till the limit of charge is reached, the surface of A facing B will be charged with negative electricity, held by attraction of the positive charge on B; conversely, the surface of B facing A will be charged with positive electricity, held by the negative on A, in

addition to the charge which it would have, if A and the dielectric were absent.

71. The areas of the armatures of three condensers, exactly alike in all other respects, are as the numbers 3, 4, 5. Explain how you would charge them with equal quantities of electricity. (1876).

If the three condensers be charged by the same number of turns of the machine, they will all be of the same potential, but the *quantity* of electricity on them will vary as the areas of their armatures, that is, it will be in the proportion 3 : 4 : 5. Since the same quantity is required to be deposited on each area we must have the equations $3qx = 4qy = 5qz$, where q is the quantity of electricity given off at each turn of the machine and x, y, z, the number of turns required. These equations are satisfied by making $x = 20$, $y = 15$, $z = 12$. Consequently, the three condensers will be equally charged from the same machine by giving it a number of turns in the proportion 20 : 15 : 12. The same may be effected by using galvanic cells in the proportion 20 : 15 : 12, or by employing a Unit jar.

72. Assuming that the quantity of electricity produced by a plate machine is proportional to the number of turns of the disc, explain how the capacities of two condensers may be compared. (1883).

The capacity of a condenser depends on (1) the

size of the coatings or armatures, (2) the thinness of the dielectric between them, and (3) the inductive capacity of the dielectric. Assuming that (2) and (3) are equal in the two condensers, as the capacity is the quotient of the quantity divided by the potential, the relative capacities of the two condensers may be found as in the answer to the preceding question.

73. Define electric induction, and show how, by its means, if we possess (to begin with) a small quantity of electricity, this may be increased indefinitely. (1876).

Induction is the name given to the influence exerted on neutral bodies by the proximity of an electrically excited one. The action of the electrophorus is due to induction, and the principle has been applied to various pieces of apparatus, such as Bennett's electrical doubler or multiplying condenser; Sir William Thomson's replenisher for his quadrant electrometer; Holtz's and other machines. It is by such instruments, actuated originally by a small inducing charge, that a small quantity of electricity may be indefinitely increased.

The following is a description of Bennett's multiplying condenser.—On the top of, or otherwise connected with, a gold leaf electroscope, is placed a flat metal plate, A; on the top of this is another similar plate, B, with its under surface varnished, and furnished with an insulating handle; this is

surmounted by a third, C, having also its under surface varnished, and similarly fitted with a handle. To use it, first put B on A, touch B with the finger, and, before removing the finger, touch the plate A with the object, the electricity of which is to be multiplied. Remove the object and the finger. Take up B by its handle, place C on B and touch C with the finger. Place B on A, touch B with the finger, and apply the edge of C to A. Remove C, take the finger from B and raise B from A. Repeat the operation several times, until so much electricity is accumulated on A as to cause the gold leaves to diverge.

74. Explain the action of a point, whether in collecting or dispersing electricity. (1864, 1872).

A point may be considered as an elongated ellipsoid or a succession of spheres gradually decreasing in size. The density on each of these spheres equals the quantity of electricity divided by their respective surfaces, and as the quantity on each is the same, the density on the smallest, *i.e.*, at the point itself, will be relatively immensely great. If a point is placed near the prime conductor of a machine in action, there will be induced on it a charge of the opposite character; this will accumulate at the point so as to produce enormous density there. The mutual attraction is sufficient to overcome the insulation of the dielectric, and the charge will be continuously *collected* away from the prime conductor. If, however, the point is

placed in the conductor, the density on it will be so great that the charge will be *dispersed* by convection.

75. Explain the action of the electrical fly (Tourniquet Electrique). (1866).

The motion is due to the repulsion between the electricity given off at the points of the fly and that imparted to the adjacent air by conduction. The repulsion between the electricity, accumulated on the points, and that of the air causes the fly to turn in a direction contrary to that in which the points are bent.

76. Explain the action of lightning conductors and the reason for making them pointed. (1860).

When a storm cloud charged with, say, positive electricity, arises, it acts inductively on the earth, repels the positive, and attracts the negative electricity, which accumulates on bodies placed on the surface of the ground and more abundantly on those which are at a greater height. The tension is greatest on the highest bodies, which are, therefore, more exposed to the electric discharge. If these are provided with points, the negative electricity flows into the atmosphere, neutralising the positive charge of the cloud. The lightning conductor, however, if the storm is violent, may be inadequate for the purpose, and the lightning strikes; the conductor, on account of its greater conductivity, receives the charge, which under

these circumstances does no damage. (See also No. 74).

77. Describe a method of determining the electric state of the air at a fixed point near to, but not in connection with, the surface of the earth. (1873).

A conductor having a flame or water-dropping arrangement at one end is connected with one pair of quadrants of a Thomson's Quadrant Electrometer. This pair of quadrants is thereby brought to the potential of the air at the spot to be tested; the other pair is connected with the earth, and the difference of potential is shown by the deflection of the needle. A gold leaf electroscope and metallic conductor may be substituted.

78. What is the law of attraction and repulsion between small bodies charged with electricity? (1882).

The force is proportional to the product of the quantities of electricity on the bodies divided by the square of their distance.

79. Two small insulated spheres, being both charged with positive electricity of the same intensity, are found to repel one another with a force of one grain. They are then both charged with positive electricity of double the former intensity; find the repulsive force which they will exert. (1864).

The force of repulsion, being equal to the product of the charges, will now be four grains.

80. Two insulated metallic spheres, being both charged with positive electricity, are found to repel one another with a force which, when the distance is considerable, varies inversely as the square of the distance. In what manner and why will this law be modified when the spheres are brought near one another? (1865).

The mutual induction between the two spheres will disturb the distribution of electricity over their surfaces, and consequently change that distribution at every change of distance, in such a way as to diminish repulsion at a given distance.

81. Two equal small spheres, charged with quantities of electricity represented by the numbers 2 and 4, attract each other with a force represented by 10, when the distance between them = 5. If the spheres are allowed to touch and then separated by a distance = 8, what force will they exert upon each other? (1875).

Charge before contact = + 4 and — 2, or — 4 and + 2,

„ after „ = 1, 1;

the force of repulsion being equal to the product of the charges divided by the square of the distance,

$$\therefore \frac{2 \times 4}{5^2} : \frac{1}{8^2} = 10 : x,$$

$$\therefore x = \frac{25}{8} \times \frac{1}{64} \times 10 = \frac{125}{256} = 0{\cdot}488$$

= force of repulsion.

82. Two small insulated metal spheres are charged with quantities of electricity in the ratio 3 : 7 respectively, and, when placed at a distance from each other equal to several times their diameter, they are found to repel each other with a certain force; they are then made to touch each other and afterwards separated to three times their former distance. Compare the force now exerted between them with that exerted before they were brought into contact. (1872).

Let a = distance at which they were first placed, then the force, as it varies inversely as the square of the distance, will be $\frac{3 \times 7}{a^2} = \frac{21}{a^2}$;

After contact the charges will be equally divided and the force will be $\frac{5 \times 5}{(3a)^2} = \frac{25}{9a^2}$

$$\therefore \text{ forces vary as } \frac{21}{a^2} : \frac{25}{9a^2} = 189 : 25.$$

83. Describe the apparatus employed by Coulomb for investigating the law of force between two small spheres charged with electricity; and illustrate by means of an example the mode of using it. (1878).

Coulomb used the torsion balance, of which a description is given in No. 16. Attached to the wire, which passes down the glass tube into the cylinder, there is, instead of a magnetic needle, a fine rod of shellac, at one end of which is a small disc of leaf copper. This rod is counterpoised so as to be always in a horizontal position. Through

the aperture in the cover of the cylinder is introduced a glass rod terminated at its lower extremity by a gilt pith ball. The ball is opposite the zero point, and before commencing the experiment the upper circle is made to read 0°; the zero points are so arranged that the pith ball and copper disc will now be in contact. The ball is then removed, electrified and replaced, when repulsion immediately takes place. In one experiment of Coulomb's the distance to which it was repelled was 36°, and in order to reduce it to 18° the index was moved through 126°, making a total torsion of the wire of $126° + 18° = 144°$. To reduce the distance to $8\frac{1}{2}°$ it was necessary to rotate the index 567°, giving a total torsion to the lower and upper parts of the wire of $567° + 8\frac{1}{2}° = 575\frac{1}{2}°$. Taking the angles of deviation as 36°, 18°, 9° and the angles of torsion as 36°, 144°, 576°, it is evident that while the first are as $1 : \frac{1}{2} : \frac{1}{4}$, the latter are as $1 : 4 : 16$, that is, that for a distance half as great the repulsive force is four times as great, and for a distance one-fourth as great the force is sixteen times as great. The force, therefore, varies inversely as the square of the distance. The force of attraction is somewhat similarly determined.

84. Define precisely what is meant by the specific inductive capacity of a substance for electricity; and describe generally how this property may be determined. (1863, 1870, 1873).

Describe the method employed by Faraday for determining the specific inductive capacity of shellac. (1879).

Faraday discovered that all dielectrics do not possess in an equal degree the power of transmitting electric force, or the same inductive capacity. Specific inductive capacity is the ratio between the capacities of two condensers of equal size, one of them being an air condenser, the other filled with the specific dielectric. This is a constant quantity for each substance, and its accurate determination is of great importance.

The following is Faraday's method of comparing specific inductive capacities. The apparatus used consists of two identical instruments of the following description. A brass sphere, connected with a knob by a metal rod insulated with shellac, is enclosed in two brass hemispheres in such a manner that an intervening space is left to contain the dielectric; the larger and smaller spheres representing the two coatings of a Leyden jar. At the commencement of the experiment the space in both instruments contains air only. The hemispheres are connected with the ground, and the knob of one of them presented to the machine, thus charging the inner sphere. By touching the knob with a proof plane, the quantity of free electricity is measured by means of the torsion balance. The knobs of the two instruments are then connected and the torsion will be one half, showing

that the charge has become equally distributed over the two spheres, since they are precisely similar. The space in the second instrument is now filled with the substance to be examined and the torsion noticed as before. The charge of the air jar will now be reduced by contact with the other, and the torsion now shown compared with the loss sustained will be the specific inductive capacity of air compared with that of the other substance examined. For example, let there be air in one instrument and shellac in the other. The torsion of the free electricity on the sphere of the apparatus containing air was found by Faraday in a certain experiment to be 290°. When the two knobs were connected, the air jar showed a density of 114° and the other 113°. In the division the induction through the air lost 176°; while that through the lac gained only 113°. Therefore the specific inductive capacity of air to that of shellac = 113 : 176 = 1 : 1·55. (Faraday, *Exp. Researches*, 1187, etc.).

85. Define the terms potential, charge, capacity, specific inductive capacity and density, as employed in electrical science. (1879, 1881, 1883).

The potential of any point is the total amount of work required to be done to bring to that point a unit of electricity from a position, so far off that no electric force acts at the point we bring it

from, if the given distribution of electricity remains unaltered.

A charge is the quantity of electrification, howsoever produced, on the surface of a body, and a body, when electrified, is said to be charged.

The capacity of a conductor is the quantity of electricity required to produce unit change of potential.

Density is the number of units of electricity per unit of area. (For specific inductive capacity, see No. 84).

D. DYNAMIC ELECTRICITY.

86. A plate of pure zinc and one of platinum are dipped into water acidulated with sulphuric acid: when the plates are caused to touch each other, what are the *visible* effects produced? State fully the chemical actions which take place at the same time. (1860).

The zinc is attacked by the acid, forming sulphate of zinc; bubbles of gas, which can be proved to be hydrogen, rise from the surface of the platinum, which is not affected by the acid. The water is, in fact, decomposed.

87. If the two plates, instead of touching directly, be united by a wire, an electrical current will pass through the latter. By what means would you prove the existence of such a current?

In what direction will it pass through the wire? What do you mean by the direction of the current and how do you suppose the word "current" came to be thus applied? (1860).

If a wire conveying a current is allowed to pass over or under a freely suspended magnetic needle, the latter will be deflected. The direction of the current will be from the platinum to the zinc, and is always assumed to be from the place of high potential to that of low. As electricity "flows" from one conductor to another along a wire or other conducting substance, the word "current" came to be applied from the analogy of water flowing through a pipe.

88. Two clean half-crowns, with a piece of cloth soaked in dilute sulphuric acid between them, produce no effect on a galvanometer. A current is sent for a moment from silver to silver through the wet cloth, the coins afterwards behave like two different metals and produce a current. Explain this. (1861).

The acidulated water is decomposed, and on the surface of the half-crown which was momentarily connected with the negative pole of the battery, a film of hydrogen is liberated next the cloth, and on the corresponding surface of the other a film of oxygen. These act as the different metals in a Voltaic cell.

89. Give a distinct statement of Volta's theory of contact and mention one or two of the weightier

objections which have been urged against it. What part did Volta ascribe to the liquid conductor which he found it necessary to introduce into his pile? (1861).

According to the contact theory, when two different metals are placed in contact, there is an electromotive force acting from one to the other, so as to make the potential of the one exceed that of the other by a certain quantity. The generation of heat, and the performance of mechanical work by the mere contact of two metals would be equivalent to a perpetual motion, and be opposed to the law which requires for the production of any power the equivalent consumption of some other power. Nevertheless, some very strong arguments have been brought forward in favour of this theory.*

Volta supposed that the wet cloth acted as a conductor as well as preventing contact between the different pairs of metals.

90. Define the terms thermal conductivity, electrical conductivity. (1876).

The greater or less facility which bodies possess for the transmission of (1) Heat, (2) Electricity. If, for instance, we take a cube, the faces of which measure one centimetre, and if one face is one degree hotter than its opposite, heat will be con-

* Sir W. Thomson, "New Proof of Contact Electricity" in the *Proceedings of the Literary and Philosophical Society of Manchester*, Jan. 21, 1862.

with a platinum wire hermetically sealed into its upper end. To the lower end of the wire is attached a plate of the same metal. The apparatus is filled with acidulated water, which is then partly decomposed by a battery, consequently one tube of each element will be partly filled with oxygen and the other with hydrogen. The battery is after a short time removed, and, as soon as a metallic connection is made between the terminals of the platinum wires, a current is set up from the oxygen to the hydrogen, both gases gradually disappearing and water being again formed.

95. Explain what is meant by a *current* and by the *direction* of a current in electricity; also how to determine the direction of the current traversing any conductor. (1863).

By the term "*current*" is meant the transference of electricity along a conductor, the ends of which are at different potentials; this necessarily tends to equalise the potentials of the two ends. From its similarity to the flow of water, the properties now possessed by the conductor cause what is called a current, and its direction is always from the place of high, to that of low, potential. The direction of a current may be determined by placing the conductor over, and parallel to, an ordinary magnetic needle. If the marked pole turns to the West, the current is going from South to North and *vice versa*.

96. State the circumstances on which the

strength of an electric current depends. (1860, 1861, 1869).

The strength of a current is proportional to the quantity conveyed in a given time, or in one second, and, if the current is constant, it is equal in all parts of the circuit.

97. State Ohm's Law. (1882).

Explain fully the meaning of Ohm's Law. (1883).

By Ohm's Law is meant that the strength, C, of the current varies directly as the electromotive force, E, and inversely as the resistance, R, of the circuit. In other words, if E is increased, C will also be greater; but if R is increased, C will be diminished, so that, always,

$$C = \frac{E}{R + r},$$

where r is the external resistance.

98. The internal resistance of a galvanic battery is equal to the resistance of 3 metres of a particular wire. Compare the quantities of heat produced, both inside and outside the battery, when the poles are connected by one metre of this wire with the quantities produced in the same time when they are connected by 37 metres of the same wire. (1871).

Let electromotive force $= 1$, then, by Ohm's law, measuring the resistance in metres of wire, $C = \frac{1}{3}$.

In the first case, $C = \frac{1}{3+1} = \frac{1}{4}$. The heat, H, disengaged being proportional to the resistance of the wire and the square of the strength of the

current $= \frac{1}{16}$, divided between battery and wire as 8 : 1.

In the second case, $C' = \frac{1}{8 + 37} = \frac{1}{40}$, and $H' = \frac{1}{1600}$, divided between battery and wire as 8 : 37.

99. Show from Ohm's law how to obtain the current of greatest strength which can be produced from a battery of a given number of cells. (1869).

Let C = strength of current, E = electromotive force, R = internal resistance of each cell, r = external resistance, and n = number of cells, then, by Ohm's law,

$$C = \frac{nE}{nR + r} = \frac{E}{R + \frac{r}{n}}.$$

This is a maximum if r be very small, which will be the case when the conducting wire is very thick.

100. Describe fully some means of measuring the strength of an electric current. (1860).

Describe any instrument for exact measurement whose action is based upon the influence of an electric current on a magnet. (1881).

The strength of a current may be measured by means of a tangent galvanometer. This, in its simplest form, consists of a circular copper band or ring of thick wire, about fifteen inches in diameter, in the centre of which is placed a small magnetic needle, not more than one inch in length. The angle to which this is deflected, when a cur-

rent is sent through the copper wire, can be read on a horizontal circle by means of a light pointer of straw or aluminium attached to the needle. The strengths of currents are proportional to the tangents of the angles of deflection. The results will be simply relative, but the values may be obtained in electromagnetic measurement by the following expression :—

$$C = \frac{HK^2}{L} \tan \theta,$$

where H is the horizontal component of the earth's magnetism at the place of observation, K the radius of the ring in centimetres, L the length of the galvanometer wire, and θ the angle of deflection.

Another (relative) mode of measuring current strength is by observing how many cubic centimetres of hydrogen are given off per minute in the electrolysis of water.

101. The internal resistance of one cell of Grove's battery is 20, while the resistance of the external wire is 2. If the intensity of the current in this arrangement be denoted by unity, what will be the intensity in an arrangement of 6 similar cells, the external resistance of the wire being still 2? (1866).

$$I = \frac{E}{20 + 2} \; \therefore \; E = 22.$$

$$\text{Intensity in 6 cells} = \frac{6E}{6 \times 20 + 2} = \frac{132}{122} = 1{\cdot}08.$$

102. Ten galvanic cells, each of internal resistance 2 and electromotive force 1·5, are connected (*a*) in a single series, (*b*) in 2 series of 5 each, the like ends of the two series being joined together. If the terminals are in each case connected by a wire of resistance 10, show what is the strength of the current in the wire in each case, and compare the rate of consumption of zinc. (1884).

$$\text{In } (a)\ C = \frac{10 \times 1 \cdot 5}{10 \times 2 + 10} = \frac{15}{30} = \frac{1}{2},$$

$$\text{In } (b)\ C = \frac{5 \times 1 \cdot 5}{\frac{5}{2} \times 2 + 10} = \frac{7 \cdot 5}{15} = \frac{1}{2},$$

∴ the consumption of zinc will be the same in each.

103. Explain the terms "Induction Current," "Extra Current," and give the conditions of the induction of a current by a current. (1874).

Induction or induced current is the term applied to that current which is produced in a conductor by a variation of current in another conductor or a magnet.

When the wire through which a current is passing is long and has many convolutions, at the instant that a current begins and ends, extra currents are induced by the action of the several parts of its circuit upon each other; that at the beginning of the current being inverse in direction, and that at the end direct.

When a current begins to flow, or receives an increase, or approaches, or is approached by, a neighbouring conductor, an inverse current is in-

duced in the latter; when the primary current ceases, or is diminished, or moved away from a neighbouring conductor, a direct current is induced in the latter.

104. Describe some one means of exciting an induced current of electricity. (1860).

An induced current may be excited by having two lengths of insulated wire coiled on the same cylinder. These may be wound side by side, or one coil may be completed before the other is commenced; in either case there is no connexion whatever between the two wires. On sending a current from a battery through the one coil, the deflection of the needle of a galvanometer will show the presence of an induced current in the other. The same effect will be produced by passing a permanent magnet through the coil.

105. State Lenz's law relating to the induction of electric currents. (1882).

When a circuit is moved in the presence of a current or a magnet, or a current or a magnet is moved in the presence of a circuit, the induced current has such a direction as to tend to stop the motion that produces it.

106. Having a permanent magnet and a coil of copper wire, state a method by which you could make an electric current circulate through the wire, and find its direction. (1866, 1878).

By suddenly placing one pole of the magnet

within the coil, an induced current will be set up in the latter, though only of momentary duration; on its withdrawal, a current in the opposite direction is temporarily set up. By attaching the coil to a galvanometer, the direction of the first current will be found to be contrary to that which circulates round the magnet according to Ampère's theory, which is that, at the north pole of the magnet, the currents circulate in a direction opposite to that of the hands of a watch, at the south pole in the same direction as that of the hands.

107. A long insulated copper wire is coiled upon a short hollow wooden cylinder. State what electrical effects would be produced in the wire by passing a long straight magnet through the cylinder, putting it in at one end and drawing it out at the other. (1871, 1878).

When the magnet is introduced, a galvanometer will show that a temporary induced current is immediately set up in the coil, in a direction opposite to that which circulates round the magnet, considering the latter as a solenoid on Ampère's theory. The galvanometer needle then returns to zero, and, when the magnet is being withdrawn, will indicate the presence of another temporary induced current in the opposite direction to the former.

108. What is meant by the specific resistance of a substance? Explain how to determine the specific resistance of a wire. (1882).

The specific resistance of a substance is the value in absolute units of the resistance of a cube of one centimetre in dimension of the substance between two opposite faces.

The specific resistance of a wire can be determined by dividing the resistance of any length and thickness of the given wire by the resistance of a piece of silver wire of the same length and thickness; the resistance of the silver wire being considered as unity.

109. What is meant by electrical resistance? (1867, 1878).

What circumstances in regard to a wire must be known before its resistance can be estimated? What is the relation between the resistance and these circumstances? (1867).

What is the resistance of a conductor? (1883).

By resistance is meant that quality of a body which tends to retard the flow of electricity. The resistance of a conductor is the reciprocal of its conductivity.

In order to determine the resistance of a wire, it is necessary to know its specific resistance, as well as its length and sectional area or weight per unit of length.

The resistance, R, of any conductor is expressed by the formula, $R = \frac{rl}{a}$, where $r =$ the specific resistance of its material, $l =$ its length, and a $=$ its sectional area or weight per unit of length.

110. Explain a method of comparing the electrical resistances of two wires. (1873, 1874).

The two wires are placed in turn in a circuit containing a tangent galvanometer, the deflection of which, caused by the battery alone, has been first noted. A comparison of the deflection of the needle caused by the introduction of each wire into the circuit will show their relative resistances, which will be in the inverse ratio of the tangents of the angles of deflection. Or a rheostat may be used. The whole of the rheostat wire is wound on the wooden cylinder, and the deflection of the needle of a galvanometer noted. One of the wires is now introduced, and the deflection again noted; this will of course be less than before. As much of the rheostat wire is unwound as will make the deflection the same as at first. The same process is repeated with the second wire. The ratio of the resistances of the two wires will be proportional to the lengths of wire unwound in each experiment. Or a set of resistance coils and a bridge may be used, as described in No. 116.

111. Compare the resistances of two copper wires, one of them 8 feet long and weighing $\frac{1}{4}$ of an ounce, the other 14 feet long and weighing $\frac{8}{7}$ of an ounce. (1873).

Resistance in wires of the same specific gravity is directly proportional to the length, and inversely proportional to the weight per unit of length or sectional area.

If W = the weight, a = the sectional area, l = the length, and R, R′ = the respective resistances, since $W = al$, $a = \frac{W}{l}$. But R varies as $\frac{l}{a}$, or, substituting for a its value in terms of W and l, R varies as $\frac{l^2}{W}$.

$$\therefore \quad R : R' = \frac{8^2}{\frac{1}{4}} : \frac{14^2}{\frac{6}{7}},$$
$$= \frac{64}{\frac{1}{4}} : \frac{196}{\frac{6}{7}},$$
$$= 256 : 228{\cdot}66,$$
$$= 1{\cdot}1195 : 1.$$

112. Using a single cell, I determine accurately the resistance of a fine platinum wire. I next apply a battery of 30 cells and make the same determination also accurately. Nevertheless the two results do not agree. State the nature of the difference and assign its cause. (1873).

By using 30 cells the wire would be much more heated by the current, hence the resistance of the wire would be greater.

113. The resistance of a piece of platinum wire l metres long and $\left(\frac{1}{m}\right)^{\text{th}}$ of a millimetre in diameter is found to be R. What will be the resistance of a bar of the same material one centimetre long and one square centimetre in section? (1877).

Resistance $= \frac{rl}{s}$, where r = specific resistance of platinum, l = the length of the wire, and s = its sectional area.

In the first case $l = 1000l$ millimetres,

$$s = \frac{\pi}{4m^2} \text{ square millimetres,}$$

$$\therefore R = 1000\, rl \div \frac{\pi}{4m^2} = \frac{4000m^2rl}{\pi}.$$

In the second case let $R' = \frac{rl'}{s'}$, where $l' = 10$ millimetres, and $s' = 100$ square millimetres,

$$\therefore R' = 10r \div 100 = \frac{r}{10};$$

$$\text{Hence } R' : R = \frac{r}{10} : \frac{4000\, m^2rl}{\pi}$$
$$= \pi : 40000\, m^2l,$$
$$\therefore R' = R\frac{\pi}{40000\, m^2l}.$$

114. The poles of a thermo-electric pile are connected by two copper wires, one 10 feet long and $\frac{1}{20}$ of an inch in diameter, the other 15 feet long and $\frac{1}{10}$ of an inch in diameter. What is the intensity of the current in each of these wires, that which would pass in the thinner wire, if the other wire were removed, being taken as unity? (1867).

Let a and b represent the two wires, then

$$\text{resistance in } a : \text{resistance in } b = \frac{10}{(\frac{1}{20})^2} : \frac{15}{(\frac{1}{10})^2}$$
$$= 10 \times 400 : 15 \times 100$$
$$= 2 \times 4 : 3 \times 1$$
$$= 8 : 3;$$

and intensity being inversely proportional to resistance we have

$$\text{intensity in } a : \text{intensity in } b = 3 : 8.$$
$$= 1 : 2\tfrac{2}{3}.$$

115. A circuit is formed containing galvanometer, battery and connecting wires, the total resistance of the circuit being 4·85 Ohms. The galvanometer shows a deflection of $48\frac{1}{2}°$. When a piece of platinum wire is introduced into the circuit, the deflection falls to 29°. From these data determine the resistance of the platinum wire, given $\tan 48\frac{1}{2}° = 1{\cdot}121$ and $\tan 29° = 0{\cdot}485$. (1878).

Let $x =$ the resistance in Ohms of the platinum wire,

$$\text{then } 4{\cdot}85 \times 1{\cdot}121 = (4{\cdot}85 + x) \times 0{\cdot}485,$$
$$11{\cdot}21 = 4{\cdot}85 + x,$$
$$\therefore x = 11{\cdot}21 - 4{\cdot}85 = 6{\cdot}36.$$

116. Explain how to compare the electrical resistances of two wires by means of Wheatstone's bridge. (1878, 1880).

Using Kirchhoff's modified form of Wheatstone's bridge, as being most convenient for the purpose, the resistances may be compared in the following way. Place in the outermost gaps of the bridge the two wires, X and Y, whose resistances are to be measured, and which we will suppose so nearly equal that, when two approximately equal resistances, A and B, are placed in the innermost gaps,

there will be a balance when the sliding block is somewhere on the fixed wire of the bridge. Balance, and note the reading, x; then interchange X and Y, balance again, and note the new reading, x'. Then if r = resistance of unit length of the fixed wire of the bridge, $X - Y = r(x' - x)$.

117. Given a cell of Grove's battery, a galvanometer and a set of resistance coils, describe how you would determine the internal resistance of the cell. (1876).

Explain how to determine the internal resistance of a galvanic battery. What advantages has Mance's method over other methods? (1880).

Describe Mance's method of determining the internal resistance of a battery. Is the method reliable, and, if not, what is the cause of its inaccuracy? Is any special precaution necessary when the resistance of a readily polarisable battery is measured by Mance's method? (1882).

The problem may be solved in several ways: the following is one. The resistance of the galvanometer must be very slight or accurately known. Connect the galvanometer and cell, and notice the deflection. Add one of the resistances from the set and again note the deflection. The two currents thus measured will be inversely as the resistances, since the electromotive force remains unchanged. If G = the resistance of the galvanometer, R = the resistance introduced, C_1 and C_2 = the strengths of currents, then we can

obtain x, the resistance of the cell, from the following:—

$$C_1 : C_2 = x' + G + R : x + G.$$

The objection to this method is that the observations are taken with different current strengths.

Another method (Latimer Clark's), which is, however, applicable only to constant batteries, is by the use of a differential galvanometer, having short thick wire. The current is passed through one of the coils, and the deflection is noted; the current is then passed through both circuits, and the needle brought back to the same deflection by the introduction into the circuit of a resistance R, then $x = R$.

Mance's method. Let A, B, C, D be four resistances arranged in circuit, B being the battery whose resistance is to be measured. A galvanometer is inserted between AB and CD, and a key between AD and BC. There is thus an ordinary Wheatstone's bridge, having a key in the usual place of the battery, and a battery in place of the ordinary resistance to be measured. The resistances are arranged so that the galvanometer is not affected whether the key is depressed or not. This is the special difficulty of the method, as it is found in practice that there is a sudden jerk, and then a slow swing, of the galvanometer needle. The former is due to the deviation of the bridge from balance, the latter to the alteration of the electromotive force. Each of these may be referred to its proper cause, for the direction of the

former can be changed by making AC—BD positive or negative, while the direction of the latter is not affected in this way. This disturbing effect is very great with one fluid batteries, on account of polarisation: it can be reduced by introducing metallic resistance into the battery circuit. Having thus reduced the effect within reasonable limits, the bridge is arranged until the deflection due to deviation from balance is opposite to that due to alteration of electromotive force. The resistances are then gradually adjusted until the needle appears to start off on its swing without a jerk. When this is effected, there is a balance, and $B = \frac{AC}{D}$. By subtracting from B the resistance put into the battery circuit, the resistance of the battery is obtained.

The advantage of Mance's method is that the battery is required to be constant during the interval only, that is occupied in raising or depressing the key.

118. Explain how the distance between the plates of a galvanic battery affects the temperature of a given wire, which connects the two poles of a battery. (1864).

The total amount of heat generated equals that generated in the cell and in the conducting wire, and varies inversely as the total resistance. If the distance between the plates is increased, the internal resistance will be greater, consequently the temperature of the wire will be less.

119. Two brass plates ten inches square are separated from each other by a plate of gutta-percha $\frac{1}{4}$ inch in thickness. How many miles of copper wire ·056 inch in diameter, will have a resistance equal to that between the plates; the specific resistance of gutta-percha being $2{\cdot}8 \times 10^{20}$ times that of copper? (1880).

Let x = length of wire in inches. Area of

$$\text{section} = \pi r^2 = \frac{22 \times (\cdot 028)^2}{7}.$$

Hence from the formula

$$R = \frac{\text{length} \times \text{specific resistance}}{\text{area of section}}$$

we have, for the wire,

$$R = \frac{7x}{22 \times (\cdot 028)^2};$$

for the gutta-percha,

$$R = \frac{\cdot 25 \times 2{\cdot}8 \times 10^{20}}{10^2} = 25 \times 28 \times 10^{15}.$$

$$\text{Hence} \quad \frac{7x}{22 \times (\cdot 028)^2} = 25 \times 28 \times 10^{15},$$

$$\therefore x = \frac{25 \times 28 \times 10^{15} \times 22 \times (\cdot 028)^2}{7}$$

$$= 10^{17} \times 22 \times (\cdot 028)^2$$

$$= 22 \times 784 \times 10^{11} \text{ inches}$$

$$= \frac{22 \times 784 \times 10^{11}}{12 \times 3 \times 1760} \text{ miles}$$

$$= \frac{49 \times 10^{10}}{6 \times 3} \quad ,,$$

$$= \frac{245 \times 10^{9}}{9} \quad ,,$$

$$= 27222222222\tfrac{2}{9} \text{ miles.}$$

120. If you had given six similar cells, say of Smee's battery, charged but not connected, in what different ways might you practically proceed to connect them? and under what circumstances would one or other mode of connection be preferable? (1865).

They might be connected so as to form a series of six cells; or of three, each consisting of two cells; or of two, each consisting of three cells; or they might be connected so as to form a single large cell. The first mode is preferable, for showing attraction and repulsion of currents, electrolysis, etc.; the last for the evolution of heat. In all cases, the best effects are obtained when the internal resistance equals the external, and, therefore, the best mode of arrangement depends on the external resistance.

121. If there are twenty cells of a battery each of a resistance of two Ohms, and if the external resistance be twelve Ohms, what arrangement of cells will give the strongest current? (1881).

The most advantageous arrangement is found from the formula, $x = \sqrt{\frac{nr}{R}}$, where $n =$ the total number of cells, $r =$ the external resistance, $R =$ the resistance of one cell, $x =$ the number of series. If x does not come out exactly, the nearest whole number must be taken.

$$\therefore\ x = \sqrt{\frac{20 \times 12}{2}} = \sqrt{120} = 10 \text{ nearly,}$$

∴ the best arrangement is in ten series of two cells each.

122. Explain how you would arrange thirty-six cells of a battery, each having an internal resistance of 1·6 Ohms, so as to send the strongest possible current through an external resistance of 5·6 Ohms. (1882).

As in No. 121,

$x = \sqrt{\frac{36 \times 5 \cdot 6}{1 \cdot 6}} = \sqrt{126} = 12$ nearly, therefore the strongest current will be obtained by arranging them in twelve series of three cells each.

123. What is meant by an electromotive series? Given a number of different metals, how would you determine their relative places in the electromotive series for a particular liquid? (1875).

In reference to their electrical behaviour, the metals have been arranged in what is called electromotive series, in which the most electro-positive are placed at the one end, and the most electro-negative at the other. When any two of these are placed in dilute acid, the current in the connecting wire proceeds from the one lower in the list to the one higher. For example, zinc, copper, silver, gold, platinum, graphite. The relative places of different metals for a particular liquid may be demined by fitting them up in cells under the same conditions and observing the effects on a galvanometer.

124. Define the term electromotive force. (1868, 1872, 1879).

When two conductors at different potentials are connected by a wire, the tendency of electricity to flow along the wire is measured by the difference of the potentials of the two bodies. The difference of potentials between two conductors or points is called the electromotive force between them.

125. The current from a battery of 10 equal elements passes through a Voltameter, and 50 cubic centimetres of hydrogen are produced in one minute. Fifty metres of wire are now introduced in addition into the circuit, and the volume of hydrogen now evolved in the Voltameter per minute is 30 cubic centimetres. If the resistance of 2·5 metres of the introduced wire be the unit of resistance and the unit of current be that which disengages one cubic centimetre of hydrogen per minute, what is the electromotive force of one element of this battery? (1868).

$$(1)\ 50 = \frac{E}{R}, \qquad (2)\ 30 = \frac{E}{R + \frac{50}{2\cdot 5}} = \frac{E}{R + 20},$$

$$\therefore E = 50\,R$$

$$\text{and } E = 30\,R + 600.$$

$$\text{Hence } 0 = 20\,R - 600,$$

$$\therefore R = \frac{600}{20} = 30,$$

and, from (1), $E = 50\,R = 1500$.

Hence, for one element, $E = \frac{1500}{10} = 150$.

126. An electric current traverses a wire. State the relations between

(1) the electromotive force, the current and the resistance;

(2) the electromotive force, the current and the heat generated;

(3) the current, the resistance and the heat generated.

Show that the third relation follows from the first and second. (1879).

A. (1) $E = CR$.

(2) $H = EC$ per unit of time.

(3) $H = C^2R$ per unit of time.

B. From (1), $E = CR$,

„ (2), $E = \dfrac{H}{C}$,

$$\therefore \frac{H}{C} = CR,$$

or $H = C^2R$.

127. A battery of electromotive force e and resistance R is employed in sending a current through a wire of resistance r, and there is no other resistance in the circuit. How much work will be done per second by the battery, and how much heat will be generated in the wire? (1881).

Assuming that e is expressed in volts, and R and r in ohms, then the current, C, in ampères,

$$=\frac{e}{R+r} \text{ or, in electromagnetic units, } = \frac{1}{10}\,\frac{e}{R+r}.$$

The work done, W, is the product of the current into the electromotive force,

$$\therefore W = \frac{1}{10}\,\frac{e^2}{R+r} \text{ ergs per second,}$$

$$= \frac{1}{10}\,\frac{e^2}{R+r} \times \frac{1}{981 \times 10^6} = \frac{e^2}{(R+r)\,981 \times 10^6}$$

kilogrammetres per second.

The heat, H, developed in the wire will be in the proportion $\frac{r}{R+r}$, therefore we have

$$\frac{r}{R+r} \times \frac{1}{10}\,\frac{e^2}{R+r} = \frac{1}{10}\left(\frac{e}{R+r}\right)^2 r \text{ ergs con-}$$

verted into heat,

$$\therefore H = \frac{e^2 r}{(R+r)^2\, 4{\cdot}2 \times 10^7} \text{ gramme-degrees per}$$

second.

128. The poles of a Grove's cell being connected with the terminals of a tangent galvanometer, a current of strength 24 was produced: the resistance of the circuit was then increased by one unit (all else remaining as before) and the strength of the current was now found to be 11. Calculate

from these data the electromotive force of the cell. (1872).

$$(1)\ 24 = \frac{E}{R}, \qquad (2)\ 11 = \frac{E}{R+1},$$

$$\therefore E = 24\ R$$

$$\text{and } E = 11\ R + 11.$$

$$\text{Hence } 0 = 13\ R - 11,$$

$$\therefore R = \frac{11}{13},$$

$$\therefore \text{from (1), } E = \frac{264}{13} = 20\ \frac{4}{13}.$$

129. How may the electromotive force of Grove's gas battery be compared with that of any other form of battery? (1876).

A tangent galvanometer and a rheostat are placed in the circuit so that the current, C, causes a certain deflection of the needle. A greater length, L, of the rheostat wire is then introduced, so that a diminished current, C′, is obtained. The cell with which the comparison is to be made is then substituted for the Grove's cell, and, by means of the rheostat, the current is first made equal to C, then, by introducing L′ length of rheostat wire, equal to C′. Let E, E′, be the electromotive forces, R, R′, their resistances when the currents are of strengths C, C′ and L, L′ the lengths of rheostat wire introduced, then

$$\text{for the trial cell } C = \frac{E}{R}, \qquad (1)$$

$$C' = \frac{E}{R+L}, \quad (2)$$

$$\text{for the comparison cell } C = \frac{E'}{R'}, \qquad (3)$$

$$C' = \frac{E'}{R'+L'}. \quad (4)$$

From (1) and (3),

$$ER' = E'R.$$

From (2) and (4),

$$ER' + EL' = E'R + E'L,$$

$$\therefore EL' = E'L,$$

$$\therefore E : E' = L : L'.$$

Hence the electromotive force of the cells compared are directly as the lengths of wire interposed.

130. Enumerate, completely, the laws of chemical action of the Voltaic current. (1877).

(1). In order to effect electrolysis, the electrolyte must be a conductor.

(2). The energy of the electrolytic action of the current is the same in all its parts.

(3). The same quantity of electricity—that is, the same electric current—decomposes chemically equivalent quantities of all the bodies which it traverses; from which it follows that the weights of elements separated in these electrolytes are to one another as their chemical equivalents; therefore

(4). The quantity of a body decomposed in a given time is proportional to the strength of the current. (*Faraday's* Laws).

131. A current of electricity is passed through a Voltameter containing acidulated water. How would you show that the quantity of water decomposed in a given time is directly proportional to the strength of the current? (1876).

By introducing into the circuit a rheostat, so that the strength of the current may be increased or diminished at pleasure, it will be found that the quantity of hydrogen liberated by electrolysis is directly proportional to the strength of the current. As oxygen is slightly soluble in water, the quantity of hydrogen only should be noted, if exact results are desired.

132. If the current of a battery of 10 Grove's cells, connected in series, is sent simultaneously through two Voltameters, containing respectively a solution of cupric sulphate and a solution of silver nitrate, and placed one after another in the circuit, show how much copper and how much silver will be deposited, while 3·25 grammes of zinc are dissolved in the entire battery. Also show how much copper and silver would be deposited, if the battery were arranged in two parallel series of 5 cells, instead of in a single series of 10 cells. ($Zn = 65·0$; $Cu = 63·4$; $Ag = 108$). (1872).

From Faraday's third law of electrolysis, in the

first case ·825 gramme of zinc will be dissolved per cell, therefore

65 : 63·4 : : ·825 : ·817 gramme of copper
and 65 : 108 : : ·825 : ·54 „ silver.

In the second case, the same quantity of zinc per cell being dissolved, each series would deposit the same quantity of copper and silver, the total of which would therefore be ·634 and 1·08 grammes respectively.

133. What is meant by Polarisation as applied to a voltaic battery, and what is its most frequent cause?

Why cannot a single Daniell's cell continue to decompose dilute sulphuric acid? Does the principle of conservation of energy afford any answer to this question? (1883).

The bubbles of hydrogen liberated at the surface of the copper plate adhere to it and form a film of gas over its surface, causing great loss of current strength. A battery in this condition is said to be *polarised*.

The electromotive force of a Daniell's cell is 1·171 volts, whereas at least 1·45 volts are necessary in order to decompose water, thereby according with the principle of conservation of energy that a certain amount of work can be done only at the expense of an equivalent amount of energy.

134. Describe an induction coil. Explain how the two induction currents are produced, and

what is meant by the *direction* of the secondary current. (1877).

There are five essential parts in an induction coil,—the core, the primary wire, the secondary wire, the condenser and the break. The core consists of a great number of pieces of thin soft iron wire, made into a firm bundle and carefully insulated. Round the core is wound the primary wire, consisting of a comparatively short length of thick insulated copper wire: each layer is well insulated by means of paraffined paper and the whole enclosed in an ebonite tube, which should be thicker at the ends than in the centre. On this is wound the secondary coil, consisting of a great length of very thin insulated wire, with its turns in the same direction as those of the primary. In very small coils the secondary is wound continuously from end to end, but in more powerful instruments it is built up in sections, each separated from its neighbour by an ebonite disc. The tension at the ends is greater than elsewhere, and it is for this reason that the insulating tube is thicker at those parts. A greater length of wire is wound in the central compartments than in those nearer the ends, since the inductive power in an electro-magnet is greatest at the centre and becomes feeble at the ends. Not only is every layer well insulated, but the whole when complete is thoroughly soaked in paraffin, so that no air spaces may be left. The size of the

wires used for the primary and secondary will depend on the size of the coil, the battery power intended to be used, and the character of spark desired. For the primary the diameter of the wire will range from 0·04 to 0·1 of an inch, and for the secondary from 0·008 to 0·004 of an inch; that of the wire composing the core, from 0·05 to 0·03 of an inch. The condenser is composed of several pieces of tinfoil and an insulating material, usually paraffined paper, placed alternately. Each piece of the insulator is larger than the metal and so arranged that one edge of every alternate piece of tinfoil may project on either side: these protruding edges are then severally soldered and a stout wire affixed. There are two forms of break, one known as the vibrating or hammer and anvil, the other the mercury, which is used only with very powerful coils; the object of either is to make and break very quickly and suddenly the current sent into the primary coil. The vibrating break is usually made so as to utilise the temporary magnetism of the core. It consists of a strong spring fastened vertically to the base of the instrument, carrying at its upper end a piece of soft iron, and at about its centre a platinum plate; a screw tipped with platinum passes through a metallic support at such a height that it may touch the plate. In the mercury break, a wire is made, either automatically, or by clock-work, or by the hand, to alternately

make and break contact with the surface of mercury. One of the wires attached to the condenser is soldered to the lower end of the spring of the vibrating break and to one end of the primary wire, the other to the pillar carrying the screw and to one of the terminals for connection with the battery. The other end of the primary is connected with the second terminal. An arrangement is also made for cutting off, or reversing the direction of, the battery current. When in action the current from the battery passes into the primary and by induction a current is set up in the secondary. But the primary current makes the core an electro-magnet, which in consequence attracts the soft iron armature of the spring, causing the platinum plate to leave the screw against which it pressed. This, it will be seen, breaks the continuity of the current; another induced current is set up and at the same time the core loses its magnetism; the spring returns to its original position, and the primary circuit is thus again completed, to be again broken and renewed so long as the battery continues in action. The extra current set up at each renewal of the primary current is in the contrary direction, but at break of contact in the same direction as the vanishing primary. When the primary current is complete and re-acts on the secondary, a great enfeeblement of the latter is the consequence, but when the primary is interrupted, the re-action not existing, there is

no enfeeblement of the secondary, the full power of which is developed; consequently we obtain discharges in a single direction only, instead of discharges alternating in direction.

185. Explain clearly the action of the iron core in increasing the induction of the primary current on the secondary in an induction coil. (1883).

The magnetisation of a soft iron core in a coil produces the same effect as the introduction of a permanent magnet into a coil, consequently it increases the number of lines of force that pass through the coils.

186. A current crosses a magnetic needle at right angles; two effects are possible—what are they? The same current is caused to run parallel to the needle, assume a direction and describe its effect. (1861, 1864).

How is a hard steel magnet influenced by an electric current traversing a wire in its neighbourhood? (1881).

If the current goes over, and at right angles to the needle, from east to west, the north pole goes to the south.

If the current goes under, and at right angles to the needle, from east to west, the intensity is increased.

If the current goes over and at right angles to the needle, from west to east, the intensity is increased.

If the current goes under, and at right angles to

the needle, from west to east, the north pole goes to the south.

Also, if the current goes over, and parallel to the needle, from north to south, the north pole goes to the east.

If the current goes under, and parallel to the needle, from north to south, the north pole goes to the west.

If the current goes under, and parallel to the needle, from south to north, the north pole goes to the east.

If the current goes over, and parallel to the needle, from south to north, the north pole goes to the west.

137. Describe the construction and explain the principles of the Astatic galvanometer. (1860, 1867, 1871, 1874, 1880).

Two magnetic needles, of nearly equal intensity, rigidly attached with their poles reversed, are suspended by a silk fibre in such a manner that one is within, and the other above, a coil of insulated wire, or each may be within a coil. The upper needle, or a pointer attached to it, indicates on a graduated circle the deflections caused by the current. It is evident (see No. 136) that both needles will, by the action of the current, tend to turn in the same direction. As the poles are reversed the force of the horizontal component is much reduced, and consequently a given cur-

rent will produce a greater deflection with an astatic than with a single needle galvanometer.

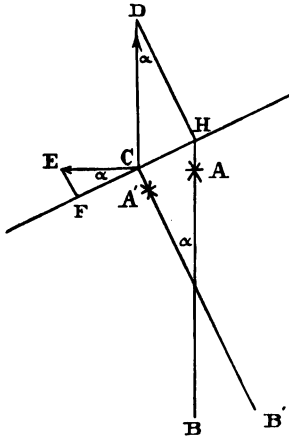
188. Describe the reflecting galvanometer. (1878, 1880).

The needle or astatic system is very light and is attached to a small concave mirror. A screen is placed at some little distance from the instrument and a scale marked on it, graduated from zero in the centre. Below the zero mark is a small hole through which the light of a lamp placed behind the screen falls on the mirror, from which it is reflected to the screen, and there the deflections of the needle are noted by observing the motions of the spot of light. The angle formed by the reflected ray will be twice the angle through which the magnet and mirror are deflected. By means of a magnet, the distance of which from the coil is adjustable within certain limits, the directive action of the earth on the needle may be increased or diminished.

189. Show that the strength of a current passing round a tangent galvanometer is proportional to the tangent of the angle of deflection. (1878).

Let AB be the direction of a needle at rest in the magnetic meridian and A′B′ its position after having been deflected through an angle a by the action of a current, also in the magnetic meridian. It is only necessary to consider the forces acting on C; these are (1) the directive force of the earth in the direction CD, and (2) the repellent force of

the current in the direction CE, and, since C is at rest, the resolved parts of these forces at right angles to CB′ will be equal and opposite. Let



these be represented by CF, CH, and at right angles to FH let FE, HD be drawn; CD and CE will then represent respectively the force due to the earth's magnetism and that due to the current.

$$\angle CDH = \angle ECF = \alpha,$$
$$CF = CE \cos \alpha,$$
$$CH = CD \sin \alpha,$$
$$\text{and } CF = CH,$$
$$\therefore CE \cos \alpha = CD \sin \alpha,$$
$$\text{or } CE = CD \tan \alpha.$$

140. A Menotti cell of 40 Ohms internal resistance is connected by thick wires with the terminals of a tangent galvanometer, formed by a single ring of stout copper wire. The deflection is 45°. Three similar cells of the same resistance are then connected in series with the first. What is the deflection of the galvanometer needle? Would any other arrangement of the four cells give a stronger current, and why? (1883).

When the three extra cells are added to the original, there will be four times the electromotive force, but also four times the resistance, therefore the deflection will still be 45°.

In accordance with Ohm's law the best effect will be obtained when they are arranged in two series of two each, for then $C = \dfrac{2E}{\frac{2R}{2}} = \dfrac{4E}{2R}$ instead of as in the former case $\dfrac{4E}{4R}$.

141. Under what circumstances is it necessary to employ a galvanometer of small resistance? (1880).

When the resistance to be measured is also small.

142. Describe some simple form of Thomson's quadrant electrometer. (1874).

Explain the principle of the quadrant electrometer, including the suspension of the needle. (1879).

Describe any instrument which may be advantageously employed for the measurement of differences of Potential. (1881).

In the simplest form of the quadrant electrometer a broad flat aluminium needle is suspended by a platinum wire having a mirror attached to it from the inner coating of an inverted Leyden jar. The needle hangs over four quadrant-shaped plates of metal, each insulated from the earth and its neighbours. The opposite pairs of quadrants are united by means of wires, and terminals are attached to them.

In the more complicated form of the instrument the Leyden jar is not inverted, the needle hangs inside a shallow cylindrical brass box cut into four quadrants, and is suspended by two silk fibres, the other ends of which are wound upon two pins, which may be turned in their sockets by a key so as to equalise the tensions of the fibres and make the needle hang midway between the upper and under surfaces of the quadrants. To the needle is attached, by a wire, a piece of platinum dipping below the surface of the sulphuric acid which forms the inner coating of the Leyden jar. There is also a replenisher (a small inductive apparatus) by which the charge of the jar can be increased or diminished at will and a gauge by which the constancy of the charge can be measured. (For a complete description see Sir. W. Thomson's *Papers on Electrostatics*, pp. 262—281).

If one pair of quadrants has a higher potential than the other, the needle will experience a force urging it from the place of high potential to that of low potential.

143. Explain how Thomson's quadrant electrometer is used to measure the electromotive force of a galvanic battery. (1874).

In order to determine the electromotive force of a battery or the difference of potential between its plates, the latter are connected with the terminals of the galvanometer, and the deflection of the needle noted.

144. A current is sent through a wire which surrounds a bar of soft iron; what occurs? Assuming a direction for the current, show by means of a sketch the polarity excited in the bar. (1860).

The soft iron will become temporarily magnetic, and that end of the bar, round which the current circulates in the same direction as the hands of a watch, will be the south pole of the magnet.

145. Describe some experiments which show that the wires conducting electric currents attract each other when the currents are moving in the same direction, and repel each other when they are moving in opposite directions. What bearing have these effects on Ampère's theory of magnetism? (1869).

To show the attraction and repulsion exercised by currents on currents, it is necessary to be provided with an Ampère's stand, or some modifica-

tion of it. The following is a description of a modified form of the instrument. In the centre of a base board, provided with levelling screws, is a circular mercury trough, divided by an insulator into two concentric channels, each of which is connected with one of two binding screws. From the centre rises a pillar terminating in a cup and supporting on a point a stout wire rectangle whose ends dip into the channels of the mercury trough. In connection with the binding screws there rise from the base of the instrument, and diametrically opposite each other, two split metal tubes into which can be fitted the ends of a larger rectangle. When currents are sent in the same direction through the two rectangles they will attract each other, but if sent in opposite directions repulsion will ensue.

Ampère's theory of magnetism is that currents circulate round magnets, and if two of these currents circulate in the same direction they are attracted, and *vice versa*. The same relations hold good of currents passing in wires.

146. A telegraphic message is transmitted between London and Edinburgh, and you are required to ascertain whether the current is directed from the former place to the latter, or *vice versa*. How would you do it? Describe, if you can, two methods of solving the problem. (1860).

(1) Insert in the circuit a galvanometer, the meaning of the deflection of which is known, say

a right hand deflection is caused when the current from London enters at one of the binding-screws. Connect that terminal to "line," and the other to earth. If the needle turns to the right the current comes from the London station.

(2) Pass the current through a solution of sulphate of copper by two wires dipping into it; the one which shows the formation of bright copper is that to which the current is directed.

147. Describe the construction of a relay; and show how, by means of it, a local battery may be put in action by a person operating at a distance. (1867).

A relay consists of an electro-magnet, one end of the wire of which receives the line current, the other end being connected with the earth. The armature of this electro-magnet works on a pivot, so that when one end is attracted by the electro-magnet, the other touches a pin in connection with a local battery. This local battery is used to work the Indicator, the armature of which follows the movements of that of the relay.

148. In the absence of iron or any other body possessing distinct magnetic properties, how would you construct an instrument which might point to the magnetic north? (1862).

If a current is sent through a solenoid, suspended on an Ampère's stand, it will point north and south. It has been found that a sinuous current destroys the effect of a straight current

of the same length as its axis; the effect of the straight portion of the current in a solenoid is therefore neutralised. Each coil will place itself at right angles to the magnetic meridian, the whole solenoid will therefore place itself so that its axis is parallel to the magnetic meridian, and its north pole will be that in which the current circulates in a direction contrary to that of the hands of a watch.

149. Describe a simple magneto-electric machine, and state the general principles on which its action depends. (1864, 1875).

A powerful battery of permanent horse-shoe magnets is fixed in a frame in such a manner that an electro-magnet may be made to revolve with its poles in close proximity to those of the permanent magnet. The presence of the steel magnet induces a temporary current in the wire composing the coils of the electro-magnet, causing in the latter a momentary magnetism. As the poles of the respective magnets separate, this temporary magnetism will disappear, to be renewed, but in the contrary direction, when, in the course of their revolution, the poles again approach each other. The soft iron cores of the electro-magnet, when thus magnetised, induce currents in the wire surrounding them in the same way as a current is induced in a helix by inserting a magnet. The ends of the wires of the electro-magnet are connected with a commutator, which has the effect of util-

ising the currents in one direction only, if required.

150. Describe a good form of Dynamo machine for sending a continuous current, and explain the use of the iron in the armature. (1882).

The Gramme machine may be taken as an example. In this there is a ring armature made of soft iron and overwound with coils of insulated copper wire, in separate sections, the ends of each coil are joined to strips of copper, insulated from each other, and fixed symmetrically as a commutator round the axis, like a split tube. This ring is rotated at a high speed between the pole pieces of powerful electro-magnets, which are called the field magnets. Metallic brushes press against the commutator to receive the current. From the position which the ring occupies in the magnetic field, direct currents are constantly generated in all the coils moving round the upper half of the ring, and inverse currents in the coils of the lower half. From this it follows that there is a constant tendency for electricity to flow round both ways from the part of the ring between the poles to the other, which latter will be at a higher potential. The strength of the induced current is increased as each coil comes up to the brushes, since the coils on each side of this position are sending their induced currents towards the same part, a continuous current is therefore generated in an external wire.

The iron in the armature reinforces the magnetic

field in that part where the wires of the movable circuit move. It also acts as a magnetic screen, protecting the internal parts of the coils from the normal action of the lines of force of the magnetic field.

151. Will the handle of a magneto-electric machine be more difficult to turn when the current is complete or when it is broken? Give a reason for your reply. (1875).

It will be more difficult to turn the handle when the current is complete. As the poles of the electro-magnet pass those of the permanent magnet, currents are set up in opposite directions, attractions ensue and difficulty will be experienced in actuating the machine.

152. State the law of the division of an electric current in two branches of a circuit, when part of the current is shunted. (1879, 1882).

The relative strengths in the two branches will be inversely proportional to their resistances. The joint resistance of a divided conductor is equal to the product of the two separate resistances divided by their sum.

153. An electrical current may pass from A to B by either of two wires ACB, ADB, the resistances of which are 8 and 7 respectively. What will be the resistance of a single wire which replaces ACB, ADB in such a way as not to produce any alteration in the current in the rest of the circuit? (1875).

Let r_1 and r_2 be the resistances of the wires ACB, ADB, and R the required resistance of the single wire,

then $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$, $\therefore$ $R = \frac{r_1 r_2}{r_1 + r_2} = \frac{3 \times 7}{3+7} = \frac{21}{10} = 2{\cdot}1.$

154. When two points in a galvanic circuit are joined by two or more conductors, state the principle of subdivision of the current. Explain how the principle is employed in the shunt to a delicate galvanometer. (1881).

For the first part see answer to last question.

When strong currents are sent through a delicate galvanometer, the deflections may be too large for accurate measurements and the instrument may be spoilt. It is therefore usual to employ a shunt through which the greater part of the current passes. The resistance of the shunt must bear a known ratio to that of the galvanometer. The resistance of the instrument when shunted will be the product of the resistances of galvanometer and of shunt divided by their sum.

155. With the shunts $\frac{1}{999}$, $\frac{1}{99}$, $\frac{1}{9}$, compare the currents in the galvanometer when any two of the shunts, and when all three, are in circuit together. (1881).

The combined resistance of

Shunts $\frac{1}{9}$ and $\frac{1}{99} = \frac{1}{108}$ of that of the galvanometer,

Shunts $\frac{1}{9}$ and $\frac{1}{999} = \frac{1}{1008}$ of that of the galvanometer,

Shunts $\frac{1}{99}$ and $\frac{1}{999} = \frac{1}{1098}$ of that of the galvanometer,

Shunts $\frac{1}{9}$, $\frac{1}{99}$ and $\frac{1}{999} = \frac{1}{1107}$ of that of the galvanometer,

and the current passing through each branch of a divided circuit is inversely proportional to its resistance.

156. A tangent galvanometer of 4 Ohms resistance forms part of a circuit whose total resistance is 80 Ohms. The galvanometer is then shunted by a wire whose resistance is 4 Ohms. Find the ratio of the currents in the galvanometer before and after it is shunted. (1879).

When a shunt is used, the resistance of which is equal to that of the galvanometer, the current passing through the galvanometer will be half of that in the instrument before the shunt is inserted. When, however, it is used in a circuit, this no longer holds strictly good, for the introduction of the shunt reduces the total resistance in the battery circuit, and therefore increases the strength of the current passing out of the battery, and it is this increased current, and not the original one, which is divided between the galvanometer and the shunt. To make up for this, what is called a *compensating resistance* is placed in the battery circuit.

157. Two wires, whose electrical resistances are as 3 to 5, are connected (*a*) in series or end to end, (*b*) abreast or in "multiple arc," and a cur-

rent of the same total strength is sent through each combination. Compare the quantities of heat produced in each wire in the two cases. (1884).

In (*a*) the current will experience a resistance of 3 + 5 = 8.

In (*b*) the current will experience a resistance of

$$\frac{3 \times 5}{3 + 5} = \frac{15}{8} = 1{\cdot}875.$$

As the heat is proportional to the resistance, in (*a*) the quantity 8 will be divided as 3 : 5, and in (*b*) the quantity 1·875 will be divided as 3 : 5.

158. Explain how an electric current may be employed (1) to determine the temperature of a furnace, (2) to assist in determining the temperature in the interior of a body which is inaccessible to a thermometer, but into which it is possible to introduce a pair of thin wires. (1881).

(1) The following arrangement is based on one devised by Siemens. After a balance has been established with a Wheatstone's bridge between four resistances, one of which is a platinum wire coiled on a porcelain cylinder, and protected by a closed tube of platinum or iron, the ratio will no longer hold good if the temperature of the platinum is increased; the other resistances must therefore be altered in order to produce a balance. The original resistance of the platinum coil being known, if the coil is placed in a furnace, the temperature of the latter can be determined.

(2) Becquerel's Electric Pyrometer may be employed for this purpose. It consists of two wires, one of platinum and the other of palladium, each two metres long and a square millimetre in section. The latter is placed in a thin porcelain tube, outside of which is the platinum; both are then enclosed in another porcelain tube, and the ends tied with thin platinum wire. This part being placed in the body, the temperature of which is to be determined, the other ends are soldered to thick copper wires that lead the current to a magnetometer, which is, in effect, a large mirror galvanometer. The deflection being known, the intensity of the current and the temperature of the junction are deduced by the aid of pyrometric tables.

E. THERMO-ELECTRICITY.

159. Describe the construction and explain the principles and application of the thermo-electric pile. (1860, 1862, 1872, 1873).

How can heat be made directly to generate an electric current? (1881).

A thermo-electric pile consists of a series of bars of two dissimilar metals, generally bismuth and antimony when the heat to be applied is not very great, soldered together at alternate ends. A

number of these couples are insulated from one another and placed in a frame in such a manner that the soldered ends are exposed. Binding screws are attached to the first antimony and last bismuth bar respectively.

If heat is applied to the soldered junctions, and wires led from the binding screws to a galvanometer of low resistance, it will be found that a current is set up, proceeding from the bismuth to the antimony; if cold is applied to the same ends, the current will go in the contrary direction.* The source of energy, therefore, is heat, which is transformed into electricity, in accordance with the principle of the conservation of energy: the work done by the current being the exact equivalent of the heat so transformed.

160. State and explain the effect produced when a strong electric current is passed for some time through a thermo-electric pile and the pile is immediately afterwards connected with a galvanometer. (1872).

If a current is sent from a battery through the points of junction of a thermo-pile in a direction from bismuth to antimony, the junction will be cooled; for, if the supply of heat to the junction causes a current to flow in a direction from bismuth to antimony, the motion of the current in that direction withdraws the heat from the junction. For similar reasons, if a current is sent from

* *Mnemonic*:—(1) BAH; (2) CAB.

antimony to bismuth the junction will get warm. The direction of the deflection of the galvanometer needle will, of course, show whether the junctions have been heated or cooled. This is called, from its discoverer, the *Peltier* effect.

161. There are two thermo-electric piles, one connected with a galvanometer containing a great length of wire and the other with one containing only a small length: find in which of these piles it would be most beneficial to increase the number of pairs. (1862).

Since it is most advantageous that the external resistance should be the same as the internal, the larger resistance of the long coil galvanometer should be met by increasing the number of pairs.

162. Describe the Thermo-pile and Reflecting galvanometer, explaining the various adjustments which combine to render the arrangement very delicate for the measurement of radiant heat. (1873).

The thermo-pile is mounted on a stand capable of being raised and placed at any angle, so that the rays of radiant heat may fall perpendicularly on the face of the pile. A polished silver cone is frequently fitted on the end of the pile. Between the pile and the radiating substances screens of various shapes and sizes are placed, and the terminals are connected with those of a galvanometer, whose resistance is duly proportioned to that of the pile.

(For a description of the Thermo-pile, see No. 159, and for that of the Reflecting Galvanometer, see No. 138).

168. When a Thermo-electric pile is introduced into the circuit of a battery, the strength of the current is reduced rather more than by the introduction of a simple wire of the same resistance as the pile. Account for this effect. (1884).

The passage of the current will in either case produce heat, which will increase the resistance of, in the one case, the metals composing the thermo-pile, or, in the other, the wire. The resistance offered by the wire will be less on account of the heat, produced in it by the current, being more easily radiated than in the pile.

MISCELLANEOUS QUESTIONS FOR PRACTICE.

1. How would you proceed to make a magnet (1) by single touch, (2) by double touch?

2. Draw diagrams showing the curves assumed by iron filings when sprinkled over (1) a bar magnet laid lengthwise, (2) two magnets placed vertically, (3) a bar magnet with consequent poles. What do we learn from these curves?

3. How would you make a magnet with consequent poles by means of a regularly magnetised bar?

4. In making a magnet to show the dip, should the bar be magnetised before or after it is centred? Why?

5. How is it that a magnet will support several pieces of iron end to end?

6. Define coercive and portative force. What is Häcker's formula?

7. Give a concise explanation of the methods employed in observing and recording the variations of the declination needle.

8. How would you make an astatic system without the aid of magnetised needles?

9. How would you counteract the influence of surrounding iron on a ship's compass?

10. In what respect does a Jamin's magnet differ from an ordinary one?

11. What effect has temperature on a magnet?

12. Describe Grove's experiment to illustrate the probable cause of the lengthening of a magnetised bar.

13. What is the "set" of a perfectly astatic system?

14. At a certain place a needle makes 71 oscillations in the same time as at another place it makes 100: compare the magnetic intensities at the two places of observation.

15. A needle under the influence of the earth's magnetism alone makes 20 oscillations in 100 half seconds, while under the combined influence of the earth's magnetism and of the pole of a certain magnet, it performs 20 oscillations in 50 half seconds; compare the force exerted on the needle by the pole of the magnet with that exerted by the earth.

16. If the needle is similarly deflected by the pole of a second magnet held at the same distance as the first, and it is found to make 20 oscillations in 30 half seconds, what will be the intensity of this pole's magnetism compared with that of the first?

17. The horizontal intensity of the earth's magnetic force is 3·89, taking as units the foot, grain and second. What is its value according to the C. G. S. system? (One inch = 2·54 centimetres; one grain = 0·064799 gramme).

18. What is the relation between electrical and thermal conductivity?

19. In what different ways may electricity be developed?

20. A crystal of tourmaline is electrically affected by the presence of a heated body; how would you arrange an experiment to show this?

21. What is the principle of Bohnenberger's gold leaf electroscope? By what modern instrument has the use of this been to a great extent replaced?

22. When using an electrical machine it is necessary to put it in metallic connection with the earth: why? What important experiment bearing upon this point did Faraday make?

23. Explain the action of the ring in Winter's machine.

24. Describe and explain the principles and action of the following machines: the Holtz, the Bertsch, the Carré, the Hydro-electric.

25. A chain is suspended from the rubber of a plate machine and the hand is placed on the prime conductor; what happens when the handle is turned?

26. How would you arrange a battery of four similar Leyden jars in order to charge them by cascade? If the first jar receives on the inside a charge $=1$, causing on the outside a charge $=0{\cdot}9$, what will be the quantity of positive electricity developed?

27. If the energy of the spark obtainable in the ordinary way from one of the above jars = 1, what will be its energy when they are arranged in cascade?

28. Show that the whole charge in a battery of similar jars charged by cascade equals only the charge of a single jar.

29. An artificial head of hair is attached to the prime conductor of a machine in action: the individual hairs separate; state and explain what happens when the hand is placed near the hair.

30. State and explain what happens when a Leyden jar is discharged in the midst of gunpowder, (1) a piece of moist string being placed in the circuit, (2) the circuit being entirely metallic.

31. The charge from a Leyden jar is sent through a wire of a certain diameter, and an exactly equal charge is sent through another wire, five times the diameter of the former; what will be the amount of heat produced, taking that in the smaller wire as unity?

32. What experiments can be performed in support of the contact theory?

33. Describe, and explain the action of, the following forms of cell: Bunsen, Smee, single fluid bichromate, chloride of silver, Leclanché, Planté's secondary.

34. Which form of cell is best suited for (1) induction coils, (2) electro-magnets, (3) electro-deposition?

35. On what does the internal resistance of a battery depend?

36. How should we be guided in the choice of a galvanometer?

37. Explain the principle of, and method of using, the sine galvanometer.

38. The current from a battery, when sent through a tangent galvanometer, produces a deflection of 20°, while that from another battery causes a deflection of 26° 30′. Compare the strengths of the two currents.

39. There are eight similar cells: in what different ways may they be connected? If the internal resistance of each cell = 4, and the external = 10, find the strength of the current in each of the different arrangements.

40. Given a battery, a set of resistances, a Wheatstone's bridge and a galvanometer: how can the resistance of the galvanometer be determined?

41. How can Ohm's law be proved experimentally?

42. A current is sent from a battery of 10 cells through (1) a voltameter containing acidulated water, (2) another containing chloride of lead, (3) another containing a saturated solution of nitrate of silver. How much hydrogen will be evolved, and how much lead and silver deposited when 13 grammes of zinc are being dissolved in each cell?

43. What are the chief objections to the use of the voltameter as a measurer of current strength?

44. A voltameter and a tangent galvanometer are included in the same circuit, and it is found that with a certain battery 60 cubic centimetres of hydrogen are evolved per minute, while the galvanometer needle is deflected 45°; how many cubic centimetres would be disengaged if the deflection of the same needle were 30°?

45. What is meant by the passive state of iron?

46. A spiral of copper wire is suspended vertically, the upper end is connected rigidly to a binding screw, the lower end touches the surface of mercury; state and explain what happens when a current is sent through the spiral.

47. A galvanometer, a copper wire and two similar metal plates separated by water are included in a circuit with a couple of Daniell's cells. The deflection of the galvanometer needle during the first few minutes is found to decrease rapidly. The cells are removed and the circuit closed; the needle is again deflected, but in the opposite direction, and gradually returns to zero. Ascribe these effects to their proper causes.

48. How would you arrange an experiment to show that different parts of the same current repel each other?

49. What effect will be produced by sending a current through a rectangular conductor which is capable of moving freely about an axis passing

through the middle of its longer side and through its centre of gravity ?

50. In making an electro-magnet how should we be governed in the choice of size and length of wire?

51. What will be the effect of interposing a copper cylinder between the soft iron of an electro-magnet and the wire ?

52. Describe the action of the syphon recorder.

53. How is the position of a fault in a cable determined ?

54. By what arrangement can a current be sent simultaneously in both directions through the same wire ?

55. How would you charge a Leyden jar by means of an induction coil ?

56. A powerful magnet is brought near a vacuum tube through which the current from an induction coil is passing. What happens ?

57. How does a paramagnetic liquid behave when under the influence of a powerful electro-magnet ?

58. Which of the following, arranged in couples, would form the most powerful thermo-pile ? which combination would give the least electromotive force ?—lead, zinc ; copper, iron ; platinum, zinc ; antimony, bismuth ; nickel, iron.

59. How would you determine the electro-motive force of a thermo-electric pile ?

60. What is the *Thomson* effect ?

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(The Miscellaneous Questions are not included in the Index).

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